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An Evaluation of Cost in Government Aircraft Acquisition Programs

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An Evaluation of Cost in Government Aircraft Acquisition Programs

by

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Dedication

I’d like to dedicate this to my parents who never stopped believing in me, always pushed me to achieve more, taught me to see all sides of an issue and never took “good enough” as an acceptable answer.

Acknowledgements

I'd like to thank the University of Texas for providing me with this opportunity, and my advisors, Dr. McCann and Dr. Nichols for their review and commentary. I'd also like to thank my co-workers and colleagues for their support and assistance in evaluating this topic and John Reynolds of NASA for his insight on the estimating process. In addition I'd like to thank Organizations like the AIAA, RAND, INCOSE, NASA, the GAO and Mitre for the work they've done to research this topic and potential improvements.

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Abstract

An Evaluation of Cost in Government Aircraft Acquisition Programs

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Aircraft system development has been steadily increasing in cost since the inception of human flight. Several factors have influenced this including economics, increasing complexity and increased customer expectations and requirements. In addition, the contractors which produce these systems have almost consistently been unable to complete them within the originally contracted budget and schedule.

The factors which influence cost increase have been studied extensively by industry, government and private organizations and a study of those findings will be conducted in the following work with the intention of determining the factors which are primarily responsible for cost increase in aircraft acquisition programs. Following the discussion of data, recommendations for reducing cost will made with the goal of

identifying the methods with which systems engineering can be used to improve the process at the system and program level. The intent will be to show how improved techniques for managing programs, meeting customer requirements and improving cost estimates can be implemented to manage cost growth. The ultimate goal of this study is to show that program risk can and should be managed more effectively and that high technology programs can be executed if they are properly managed.

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Abbreviations

A-12	MacDonald Douglass Carrier Based Stealth Bomber
ACWP	Actual Cost of Work Performed
AESA	Active Electronically Scanned Array
AoA	Analysis of Alternatives
ATF	Advanced Tactical Fighter
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
C-17	Lockheed Cargo and Transport Aircraft
C-5 RERP	Lockheed Cargo Aircraft
CAIV	Cost as an Independent Variable
CDD	Capability Development Document
CDR	Critical Design Review
CER	Cost Estimating Relationship
CPI	Cost Performance Index
CTE	Critical Technology Element
DAG	Defense Acquisition Guidebook
DAP	Defense Acquisition Process
DAU	Defense Acquisition University
DCGF	Development Cost Growth Factor
DoD	Department of Defense
EH-101	Augusta Westland Helicopter
EMD	Engineering and Manufacturing Development
EVMS	Earned Value Management System
F/A-18 E/F	MacDonald Douglass Fighter Aircraft
F/A-22	Lockheed Martin Fighter Aircraft
F-117A	Lockheed Stealth Ground Attack Aircraft
F-14	Grumman Maritime Air Superiority Fighter
F-15	MacDonald Douglass Air Superiority Fighter
F-16	General Dynamics Multi-Role Fighter
FRP	Full Rate Production
FSD	Full Scale Development
GAO	Government Accountability Office
Global Hawk	Northrop Grumman Unmanned Aerial Vehicle
HS I	Human System Integration
ICD	Initial Capabilities Document

IMP	Integrated Master Plan
IMS	Integrated Master Schedule
INCOSE	International Council on Systems Engineering
IOC	Initial Operating Capability
IOT&E	Initial Operational Testing and Evaluation
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
JSF	Joint Strike Fighter
KPP	Key Performance Parameter
LCSP	Life Cycle Sustainment Plan
LHX	Light Helicopter Experimental
LRE	Latest Revised Estimate
LRIP	Low Rate Initial Production
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MR	Management Reserve
MS A	Milestone A
MS B	Milestone B
MS C	Milestone C
NASA	National Air and Space Administration
OBS	Organizational Breakdown Structure
P-BEAT	Performance Based Estimate Analysis Tool
PDR	Preliminary Design Review
RAH-66	Sikorsky Helicopter
RFI	Request for Information
RFP	Request for Proposal
S&T	Science and Technology
SAR	Selected Acquisition Reports
SEP	Systems Engineering Plan
SoS	System of Systems
SR-71	Lockheed Supersonic Spy Plane
SRR	System Requirements Review
TAB	Total Acquisition Budget
TEMP	Test and Evaluation Master Plan
TRL	Technology Readiness Level
TUF	Technical Uncertainty Factor
U-2	Lockheed Spy Plane
V-22	Bell/Boeing Tilt Rotor Aircraft
VH-3D	Sikorsky Presidential Helicopter

VH-60N	Sikorsky Presidential Helicopter
VH-71	Presidential Helicopter
WBS	Work Breakdown Structure
VXX	Presidential Helicopter Development Program
YF-22	Lockheed Martin Technology Demonstrator
YF-23	Northrop Technology Demonstrator

1.0 Introduction

Cost increase in aircraft programs is a big topic in the media today. During the recent U.S. Presidential Election the new Lockheed Martin / Augusta-Westland VH-71 Presidential Helicopter became a hot issue during an election year rocked by a large scale recession (Colvin, Reuters). The VH-71 Presidential Helicopter which had suffered a cost over-run of 50% was cancelled in 2009 as a statement against “Government Procurement Run Amok” (Drew, NYT; Colvin, Reuters).

In RAND Report MG696 Mark V. Arena summarizes the state of Military Aircraft Procurement by quoting Norman Augustine as saying:

> In the year 2054, the entire defense budget will purchase just one aircraft. The aircraft will have to be shared by the Air Force and Navy 3½ days per week except for leap year, when it will be made available to the Marines for the extra day.

Augustine, a former president and CEO of Lockheed Martin, is noted as having made the remark with reference to the ever rising cost of aircraft development in his work “Augustine's Laws” (Arena, 1).

Aircraft system development has been steadily increasing in cost since the inception of human flight. Several factors have influenced this including economics, increasing complexity and increased customer expectations and requirements. In addition, the contractors which produce these systems have almost consistently been unable to complete them within the originally contracted budget and schedule.

Methods for reducing cost increase in system development and manufacturing have been studied extensively by both government and industry, but the question becomes whether they are targeted in the right direction.

Glenn Havskjold points out that an extensive list of potential methods for reducing cost was published in 1998 as the "Concurrent Engineering Body of Knowledge," which consisted of 84 individual methods for improving cost performance. However, as Havskjold put it, many companies will simply chose improvement programs without determining whether that which is selected is, "Necessary or Sufficient to make a significant difference at the program level." In addition, he states that programs following this approach generally, "Fall victim to the product development law of unintended consequences: "That which is focused on is improved; everything else suffers" (Havskjold, 2). With this in mind, Havskjold recommends that in order to reduce the cost increase of new systems one must first identify the cause of the problem and then determine the methods required to attack it.

The factors which influence cost increase have been studied extensively by industry, government and private organizations and a study of those findings will be conducted in the following work with the intention of determining the factors which are primarily responsible for cost increase in aircraft acquisition programs. Based on the results of the study recommendations will be made for processes which can be implemented to improve acquisition programs in the future.

The discussion which follows will start by providing a brief overview of the Government Acquisition Process in order to define the phases and milestones during individual acquisition programs. The Aircraft Design Process will be discussed in order to provide an overview of the phases involved in producing a new aircraft as well as to highlight the differences between the process for commercial and government programs. A study will then be conducted to evaluate the causes which drive the increasing cost of aircraft development programs as well as the factors which result in cost growth over initial program estimates. The discussion will then move to the Nunn McCurdy process which was introduced in 1982 in order to improve oversight of defense acquisition programs at the congressional and Department of Defense (DoD) levels. In brief, the Nunn McCurdy process requires the DoD to terminate programs which exceed specific thresholds above original program estimates. An evaluation will be made of available data on Nunn McCurdy breaches in order to determine if trends exist in the primary cases cited for individual breaches. An evaluation of three recent aircraft development programs will then be undertaken in order to determine the primary factors which resulted or prevented cost increase in each case. Following the discussion of data, recommendations for reducing cost will made with the goal of identifying the methods with which systems engineering can be used to improve the process at the system and program level.

Overall, as Mark Arena put it in RAND MG-696, “The escalating cost of aircraft and the downward cycle of procurement rates raise issues about the number of aircraft [the] DoD will ultimately be able to procure and operate” (Arena, 4). Further, the ability to control cost increase in these systems becomes even more relevant when one considers the actions being taken by congress in response to uncontrolled growth.

2.0 The Defense Acquisition Process

The Defense Acquisition System is developed with the purpose of procuring the best solution for meeting the needs of the warfighter. The following excerpt from the forward of the Defense Acquisition Guidebook (DAG) summarizes the mission:

> In that context, our continued objective is to rapidly acquire quality products that satisfy user needs with measurable improvements to mission capability at a fair and reasonable price. The fundamental principles and procedures that the Department follows in achieving those objectives are described in DoD Directive 5000.01 and DoD Instruction 5000.02.

The system sets forth a framework for program development which is composed of milestones and checks to evaluate the readiness of a proposed system to move on to the next phase of development. The Defense Acquisition Guidebook, prepared by the Defense Acquisition University (DAU), is a primary reference for program managers in major defense programs. The DAG is a reference which outlines in detail the procedures, deliverables and expectations for meeting the mandatory requirements of DoD Instruction 5000.02. In addition the guide provides detailed discussion of background information and Federal Acquisition Requirements for each topic.

As described in DoDI 5000.02, The Defense Acquisition System consists of five primary phases and three primary milestones. Within the primary phases and milestones are several other milestones related to systems engineering, logistics, manufacturing and other relevant areas of system development. Evolutionary Acquisition is a process defined by the DoD which Segments a Proposed Materiel Solution into a series of Development Programs, each of which has its own series of phases and Milestones. As explained in DoDI 5000.02, the advantage of Evolutionary Acquisition lies in the ability to meet the needs of the warfighter quickly …

An evolutionary approach delivers capability in increments, recognizing, up front, the need for future capability improvements. The objective is to balance needs and available capability with resources, and to put capability into the hands of the user quickly. The success of the strategy depends on phased definition of capability needs and system requirements, and the maturation of technologies that lead to disciplined development and production of systems that provide increasing capability over time.

Figure 2.1 shows a flow diagram of the defense acquisition system including the relevant milestones and phases and Figure 2.2 details the evolutionary acquisition process.

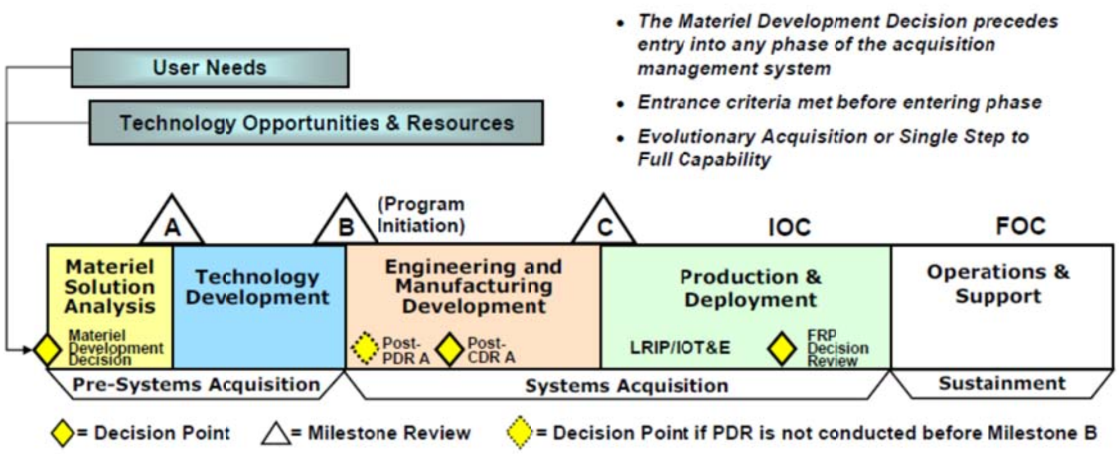

Figure 2.1 – The Defense Acquisition Management System (DoDI 500.02)

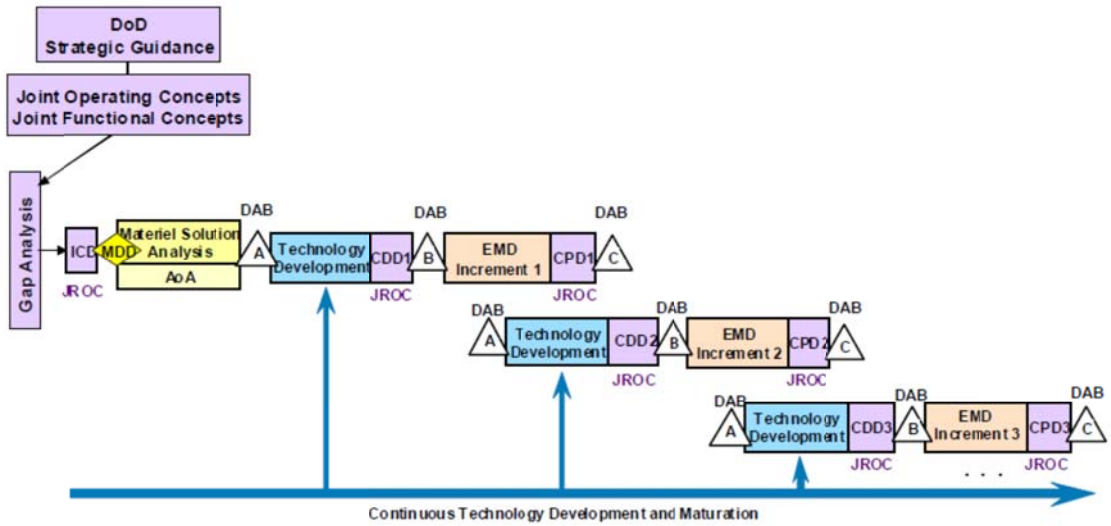

Figure 2.2 – The Evolutionary Acquisition Process (DoDI 5000.02)

The primary phases of Defense Acquisition Process (DAP) are Materiel Solution Analysis, Technology Development, Engineering and Manufacturing Development, Production and Deployment and Operations and Support. There are also three primary milestones in the process; milestone A approves the transition to Technology Development, Milestone B approves the Transition to Engineering and Manufacturing Development and Milestone C approve the transition to Full Rate Production. Each of these phases has specific goals and deliverables which must be met in order to move on to the next phase. At each phase of the DAP contractors must meet specific technical and manufacturing requirements while also preparing documents and plans required to meet regulatory and oversight requirements. The basic intent and requirements of each phase are summarized in the table which follows.

Summary by Phase (Excerpts quoted from the DoD 5000.02)

Phase or Milestone	Description
Materiel Solution and Analysis	The purpose of this phase is to assess potential materiel solutions and to satisfy the phase-specific entrance criteria for the next program milestone designated by the Milestone Decision Authorities (MDAs). Entrance into this phase depends upon an approved Initial Capabilities Document (ICD) resulting from the analysis of current mission performance and an analysis of potential concepts across the DoD Components, international systems from allies, and cooperative opportunities. The Materiel Solution Analysis Phase ends when the Analysis of Alternatives (AoA) has been completed, materiel solution options for the capability need identified in the approved ICD have been recommended by the lead DoD Component conducting the AoA, and the phase-specific entrance criteria for the initial review milestone have been satisfied.
A	Decision to Proceed to Technology Development
Technology Development	The purpose of this phase is to reduce technology risk, determine and mature the appropriate set of technologies to be integrated into a full system, and to demonstrate Critical Technology Elements (CTE)s on prototypes. Technology Development is a continuous technology discovery and development process reflecting close collaboration between the S&T community, the user, and the system developer. It is an iterative process designed to assess the viability of technologies while simultaneously refining user requirements.
B	Decision to Move to Engineering and Manufacturing Development
Engineering and Manufacturing Development	The purpose of the EMD Phase is to develop a system or an increment of capability; complete full system integration (technology risk reduction occurs during Technology Development); develop an affordable and executable manufacturing process; ensure operational supportability with particular attention to minimizing the logistics footprint; implement human systems integration (HSI); design for producibility; ensure affordability; protect CPI by implementing appropriate techniques such as anti-tamper; and demonstrate system integration, interoperability, safety, and utility. The CDD, Acquisition Strategy, SEP, and Test and Evaluation Master Plan (TEMP) shall guide this effort. Entrance into this phase depends on technology maturity (including software), approved requirements, and full funding. Unless some other factor is overriding in its impact, the maturity of the technology shall determine the path to be followed. EMD has two major efforts: Integrated System Design, and System Capability and Manufacturing Process Demonstration. (con't)

Table 2.1 – Defense Acquisition Process Phases

Phase or Milestone	Description
Engineering and Manufacturing Development (continued)	Phases Integrated System Design. This effort is intended to define system and system-of-systems functionality and interfaces, complete hardware and software detailed design, and reduce system-level risk. Integrated System Design shall include the establishment of the product baseline for all configuration items. Integrated System Design ends with a successful Post-CDR Assessment. System Capability and Manufacturing Process Demonstration. This effort is intended to demonstrate the ability of the system to operate in a useful way consistent with the approved KPPs and that system production can be supported by demonstrated manufacturing processes. The completion of this phase is dependent on a decision by the MDA to commit to the program at Milestone C or a decision to end this effort.
C	Decision to Move to Production and Deployment
Production and Deployment	The purpose of the Production and Deployment Phase is to achieve an operational capability that satisfies mission needs. Operational test and evaluation shall determine the effectiveness and suitability of the system. Entrance into this phase depends on the following criteria: acceptable performance in developmental test and evaluation and operational assessment; mature software capability; no significant manufacturing risks; manufacturing processes under control; an approved Capability Production Document (CPD); a refined integrated architecture; acceptable interoperability; acceptable operational supportability; and demonstration that the system is affordable throughout the life cycle, fully funded, and properly phased for rapid acquisition. Phases Low Rate Initial Production (LRIP) This effort is intended to result in completion of manufacturing development in order to ensure adequate and efficient manufacturing capability and to produce the minimum quantity necessary to provide production or production-representative articles for IOT&E, establish an initial production base for the system; and permit an orderly increase in the production rate for the system, sufficient to lead to full-rate production upon successful completion of operational (and live-fire, where applicable) testing. Full Rate Production Continuation into full-rate production results from a successful Full-Rate Production (or Full Deployment) Decision Review by the MDA. This effort delivers the fully funded quantity of systems and supporting materiel and services for the program or increment to the users. During this effort, units will typically attain Initial Operational Capability (IOC).

Table 2.1 Cont. – DAP Phases

Phase or Milestone	Description
Operations and Support	The purpose of the Operations and Support Phase is to execute a support program that meets materiel readiness and operational support performance requirements, and sustains the system in the most cost-effective manner over its total life cycle. Planning for this phase shall begin prior to program initiation and shall be documented in the LCSP. Operations and Support has two major efforts, Life-Cycle Sustainment and Disposal. Entrance into the Operations and Support Phase depends on meeting the following criteria: an approved CPD; an approved LCSP; and a successful Full-Rate Production (FRP) Decision. Phases LIfe Cycle Sustainment Life-cycle sustainment planning and execution seamlessly span a system's entire life cycle, from Materiel Solution Analysis to disposal. It translates force provider capability and performance requirements into tailored product support to achieve specified and evolving life-cycle product support availability, reliability, and affordability parameters. Disposal At the end of its useful life, a system shall be demilitarized and disposed of in accordance with all legal and regulatory requirements and policy relating to safety (including explosives safety), security, and the environment.

Table 2.1 Cont. – DAP Phases

The requirements for each phase are extensive and are only be briefly described here. The complete requirements for each phase of the development process can be found in the DAG and DoDI 5000.02 (2008). For all new queries into documentation requirements at each phase the DAG should be referenced directly. The Defense Acquisition Guidebook is a Dynamic Document which is updated, as required for changes in policy. Figure 2.3 shows a timeline of DAP Document Revisions and Standards Changes since 1960. From the timeline it should be noted that the primary reference for the Defense Acquisition Process has changed three times since 1967 (when the DoDI 7000.2) was initially released with the first change (from the 7000.2 to the 5000.2) in 1991.

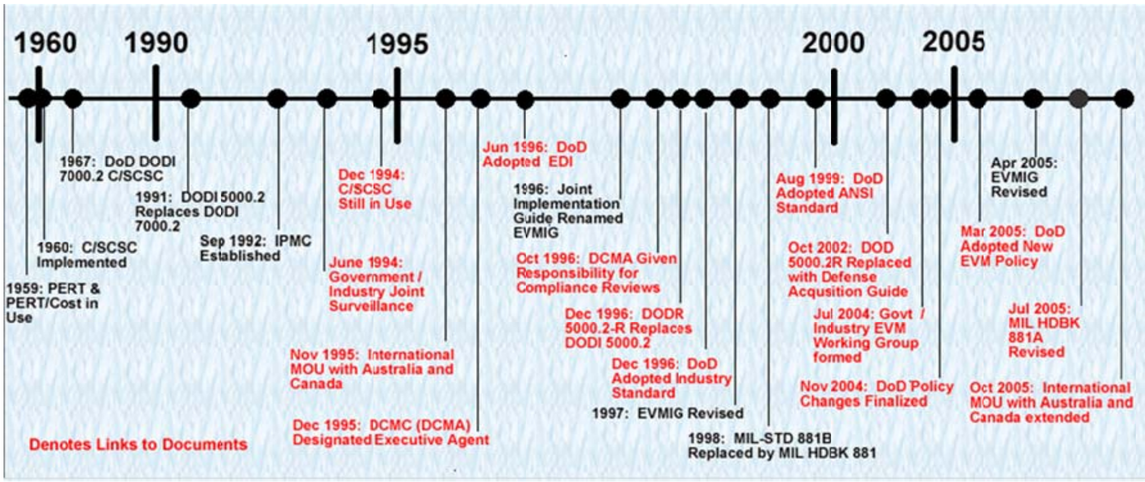

Figure 2.3 – Defense Acquisition Process Updates (EVM DAU)

The Defense Acquisition System is the standard used by the DoD to procure advanced systems. It has several primary phases and milestones and defined reporting requirements for each. The system has been developed from the outset with the intent of providing capability to the warfighter quickly and at a fair and reasonable price with the emphasis going forward on the evolutionary acquisition process which is intended to develop future systems on an incremental basis allowing for more adaptive procurement. For more information please consult the resources listed in Appendix A.

3.0 The Aircraft Development Process

The aircraft development process starts with a set of mission requirements defined by the end user either through market studies or a formal request for proposal from a government procuring body. The formal Aircraft development process then comprises several stages as shown in Figure 3.1. In its simplest form the design process consists of Conceptual Design, Pre-Design and Final Detail Design and the overall development process consists of design, manufacturing and qualification / certification (Havskjold, 6).

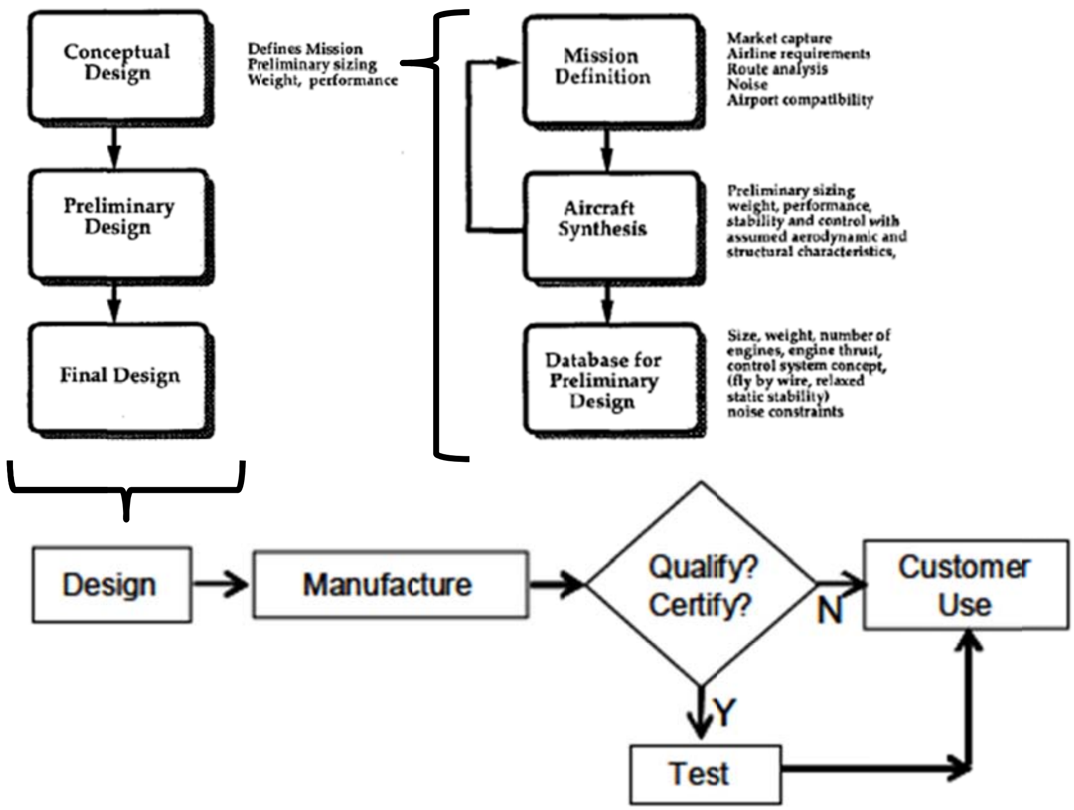

Figure 3.1 – Aircraft Development Cycle (Havskjold)

During the aircraft design phase the Design Organization must determine factors such as the intended or desired use, type of flight, number of passengers, usable load, range etc. and then determine the method through which those criteria will be implemented to generate a safe and airworthy aircraft. In any aircraft development program the three primary drivers are weight, performance and cost. Increased weight reduces performance, but decreasing weight increases cost. Likewise, it can generally be argued that increasing performance can also increase weight unless cost is also increased. During the manufacturing phase the initial prototypes are created and the manufacturing processes are developed. The development of manufacturing processes is frequently conducted in parallel with the design effort such that as the design for individual components and systems is completed the manufacturing processes are then developed. A more detailed diagram of the process is shown in Figure 3.2 which details a typical Development Process for a Civilian Aircraft (Desktop Aeronautics).

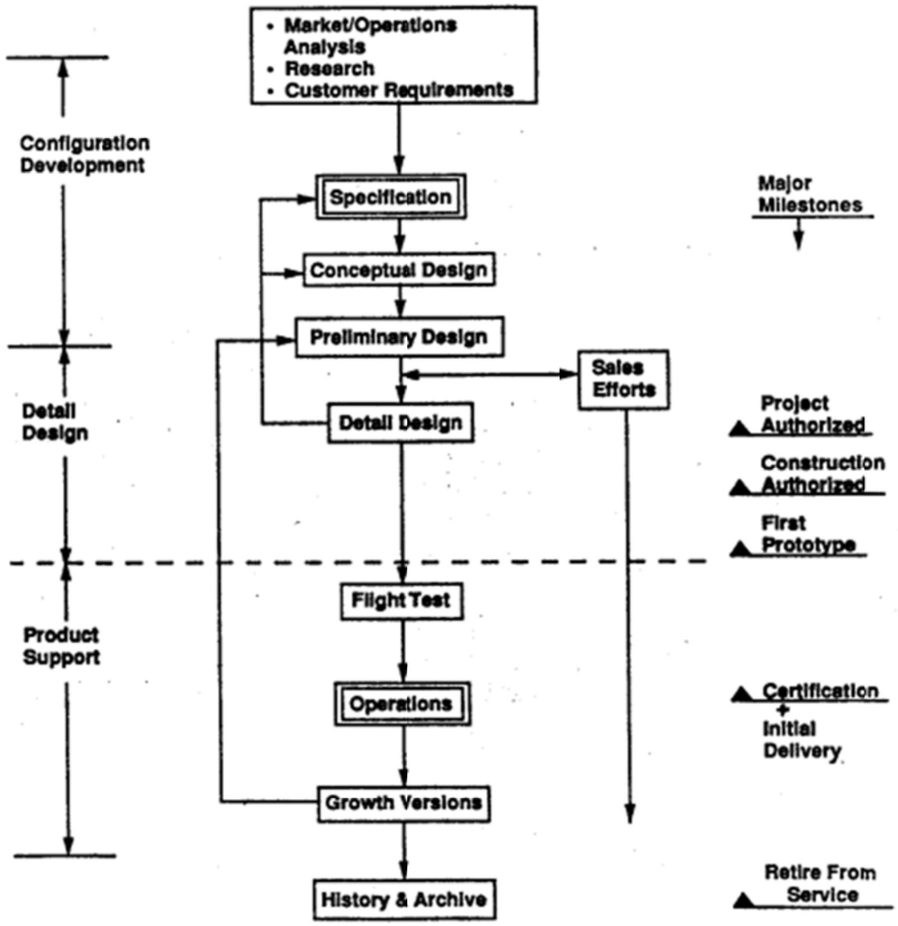

Figure 3.2 – Aircraft Development Cycle (Desktop Aeronautics)

In government development programs the overall airworthiness criteria is similar to that of civilian programs, with exceptions related to maneuvering loads and mission specific requirements. The primary exception in military program, however, is that the specification for the Air Vehicle and the requirements for qualification are dictated by the procuring agency such as the Navy or Air Force. When purchasing an aircraft the procuring body will generate a requirements specification detailing the mission requirements for the aircraft as well as the type of aircraft required and the required methods for verification of the stated requirements. The Air Vehicle specification will also call additional documents including Military and Industry Specifications, Standards and Handbooks which impose additional requirements on the operation and performance of the Air Vehicle and systems as well as the required methods for performance verification. In “Airplane Cost Estimation: Design, Development, Manufacturing and Operating,” Dr. Jan Roskom details the Comparison between a Civilian and Government Procurement Program during the Planning and Conceptual Design Phases. As shown in Figure 3.3, the primary difference from a design perspective occurs in the planning phase. During the planning phase the contractor (company that builds the aircraft) will iterate on the basic design configuration with the government customer until an initial design is reached. This is generally conducted through a request for information (RFI) from the government procuring body to the aircraft industry. Following the Initial Design Trades the Government will issue the Request for Proposal (RFP) containing the official Mission Specification which will then drive the conceptual design process.

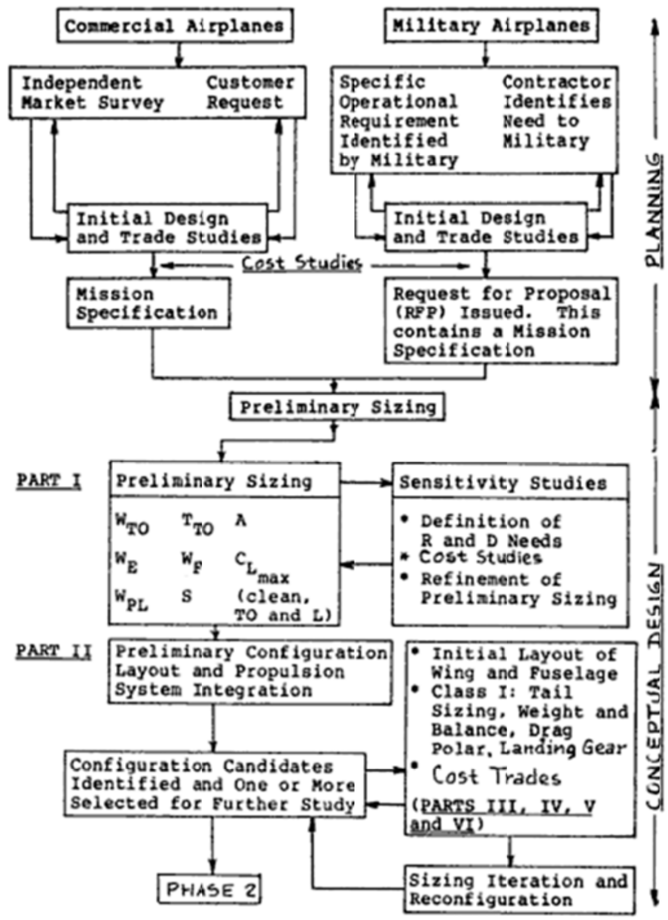

Figure 3.3 – Aircraft Development Cycle – Planning and Conceptual Design (Roskom)

The Contracted companies which will produce the aircraft will also be required to follow the processes outlined in the DoD specified Defense Systems Acquisition Process (DAP) discussed in Section 2. To draw a parallel to the DAP, the Initial Design or Planning and Conceptual Design Phase will begin during the Material Solution Analysis Phase of the DAP and extend into the Technical Development Phase. The Contracting Agency (Air Force, Navy …) will initiate the process by requesting proposals for systems capable of meeting mission requirements. Contractors will then respond to the request with detailed technical descriptions of systems that meet the customer's requirements and bids for system development and cost following conceptual design.

Following the Initial Concept Development the Contracting Body would then down select to one or more designs and enter the Technology Development Phase where the contractor would develop and refine the design and potentially build a demonstration prototype. As an example, during the Development of the Advanced Tactical Fighter (ATF) Aircraft two competing designs, the YF-22 and YF-23 were selected for prototyping or Full Scale Development (FSD) in the Technology Demonstration Phase. The winner of the final design evaluation, the Lockheed Martin F-22 Raptor was awarded a contract for Engineering and Manufacturing Development at Milestone B (Sometimes Milestone II). On the contrary, in the LHX Program two proposals were competed at the concept stage but only one aircraft, the RAH-66 Comanche from Boeing/Sikorsky was chosen for FSD during the Technology Development Phase (Global Security).

In Government Acquisition Programs the Design and Initial Testing of the new aircraft are conducted during the Engineering and Manufacturing Development (EMD) Phase. During this phase, following Milestone B approval of the Aircraft Design, the design organization prepares the production design and develops the manufacturing processes and tooling. The initial aircraft produced are then used to complete qualification testing of the design. A schedule for a representative engine development program moving from Technology Development to EMD is shown in Figure 3.4. The government equivalent of certification, commonly referred to as qualification, is primarily completed during the EMD phase of the Aircraft Development Program. During this phase the contractor is required to simultaneously verify the manufacturing processes which will be employed during the production and deployment phase while also demonstrating through test, “That the system meets the contract specification requirements and satisfies the operational and mission needs” (Skira, 2). The certification authority during this process will be the representatives of the associated procuring body, generally the Navy or Air Force.

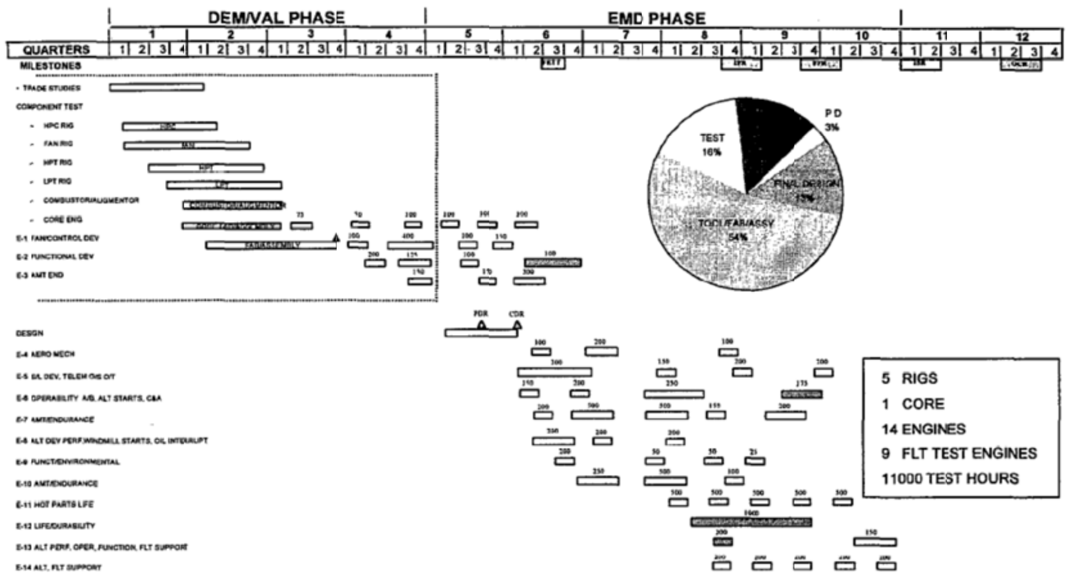

Figure 3.4 – Notional Aircraft Turbine Engine Development Program (Skira, 5)

Following the certification or qualification process, the air vehicle is approved for production and customer use subject to the restrictions noted in the flight manual. Flight manuals are produced as part of the Air Vehicle qualification process and contain performance envelopes for safe aircraft operation which have been confirmed by flight testing. Assuming that the customer has approved the performance of the air vehicle at Milestone C, the aircraft now moves into the Production and Deployment Stage. During the first phase of production known as Low Rate Initial Production (LRIP) the manufacturing processes developed during the EMD phase will be verified and the Air Vehicle will undergo Initial Operations Testing and Evaluation (IOT&E). During IOT&E the customer will test the aircraft in mission specific conditions to verify that the aircraft will meet mission requirements. Following the Successful completion of LRIP and IOT&E the Air Vehicle will be approved for Full Rate Production therefore completing the development cycle.

The Aircraft Development Cycle begins with a set of mission requirements defined either by the prevailing market or a government customer and progresses through the Conceptual and Pre-Design phases to Final Design and Manufacturing Development. After the initial prototypes are built the design is tested and certified or qualified and then produced for customer use. In military acquisition programs the Design phases are divided between the Materiel Solutions Analysis, Technology Development and Engineering and Manufacturing Development Stages. The test and certification stages of the development process are then completed under the umbrella of the EMD phase and upon completion of certification the design is given the approval for production at Milestone C. Military aircraft have some additional testing requirements, referred to as Initial Operational Testing & Evaluation to complete in order to move on to Full Rate Production but overall the basic Process of Commercial and Military Aircraft Design is very similar.

In the next section an evaluation of factors contributing to the increasing cost of aircraft development and production will be conducted during which it will be shown that the primary difference between the civilian and military aircraft is the general complexity of the design driven by increased performance requirements.

4.0 Evaluating Cost Increases in Development Programs

Cost Increases in Aircraft Development have become a very serious issue. In, "Developing Innovative Products on Budget and On Schedule – Part 1 …,"Glenn Havskjold highlights the severity of the situation by quoting the following from the Acting Deputy Secretary of Defense who was in the process of authorizing a study of acquisition process (Havskjold, 2):

> There is a growing and deep concern within the Congress and within the Department ofDefense (DoD) Leadership Team about the DoD acquisition processes. Many programs continue to increase in cost and schedule even after multiple studies and recommendations that span the past 15 years…By this memo, I am authorizing an integrated acquisition assessment…
>
> The committee is concerned [about] underperformance of major weapons programs… Problems occur because Department of Defense's weapon programs do not capture early on the requisite knowledge that is needed to efficiently and effectively manage program risks…
>
> …The committee is concerned that the current Defense Acquisition Management Framework is not appropriately developing realistic and achievable requirements within integrated architectures for major weapons systems based on current technology, forecasted schedules and available funding…

In addition, as part of this report industry representatives also expressed concern

> Defense contractors bear a significant share of the blame for cost overruns in major U.S. weapons programs, said Ronald D. Sugar, chairman and chief executive of Century City-based Northrop Grumman Corp…."We're a big part of the problem … The significant accountability on our part for overruns" traces to "a failing to do what we said we would do and being too optimistic going into it."

In summary, the available data on cost for acquisition programs indicates that the overall cost of aircraft development programs is rising and further, that a clear trend of cost overruns exists. Several industry and private organizations including the AIAA and the RAND Corporation have published numerous studies outlining the overall situation as well as the individual causes. The Data and Results from several of these studies have been reviewed and compiled with the intent of providing an overview of the work conducted for comparison. Overall, the work reviewed indicates that the primary drivers of cost increase in development programs result from several different factors including, but not limited to, the economic environment, requirements changes, technical difficulty, technical complexity, and estimating and planning.

In order to discuss increasing Aircraft Cost one must first note that cost increases as discussed in the literature can be categorized in two different ways, cost escalation (program to program) and cost growth over initial estimates (individual program). In the research available on the topic one can find studies that address both issues. Cost Escalation in the price of aircraft, independent of that due to inflation, will overall result in reduced acquisition capability over time while Cost Growth in individual systems will ultimately further reduce the ability to acquire the desired number of aircraft or result in negative impacts in other areas of the budget. In the following evaluation individual studies will be presented with the intent of clarifying the topics of Cost Escalation and Cost Growth as well as outlining the causes of each. The topic of Cost Growth has been studied extensively and a significant amount of data exists on the topic. With that in mind the following evaluation will segment the topics of Cost Escalation, Cost Growth, Escalation of Cost Growth and Causes of Cost Growth in order to preserve the organization and continuity of the discussion.

4.1 Cost Escalation

Cost Escalation is the increase in cost of delivered aircraft systems of the same type over time or stated a different way; cost escalation is the increase in cost for new models of the same type of aircraft. This can be compared to other consumer phenomenon such as the increasing cost of new technology items such as televisions or cars. Overall cost escalation is due to economic factors, like inflation, and customer driven factors such as new capabilities and features.

In RAND MG-696 “Why has the Cost of Fixed-Wing Aircraft risen?” Mark Arena classifies the reasons for increasing cost of new programs into Economic Factors and Customer Driven Factors (Arena, xvii) noting that Economic Factors are associated with labor, materials and equipment while Customer Driven Factors include Contractual Issues such as quantity ordered and technical aspects such as changing requirements and increasing technological demand (Arena, 4). In order to classify the primary contribution of each factor Mark Arena compiled a database of cost, quantity, technical and economic data from a variety of sources on 116 aircraft programs with the goal of quantifying cost growth since the 1970s. The data was then evaluated to determine the contribution from both economic and Customer Driven Factors, noting that it’s been normalized both for inflation and changes in quantity procured. Through this study it was found that the cost increase due to purely economic factors was on average 3.5% annually (Table 4.1) which, it is noted, is on par with the relative rate of inflation (Arena, 32). More significantly though, the increased cost due to customer driven factors ranged from 2 to 12% (Arena, 52). The total average cost escalation for the aircraft platforms evaluated, seen in Table 4.2, ranges from 6 to 12% annually. Notable observations made by Arena are the Low Impact of Economic Factors, the positive impact of increased production and the correlation between platform complexity and overall cost. To determine the effectiveness of the evaluation Arena evaluates a series of pair-wise comparisons for comparable aircraft and presents a cost escalation analysis comparing predicted values for cost escalation to new aircraft models to actual data for cost escalation and shows that overall the results compare favorably (Table 4.3).

Contributions of the Economic Factors to Cost Escalation for a Notional Example

Economic Factor	Contribution to Annual Rate of Increase, %
Labor	0.8
Material	1.3
Equipment	1.1
Fees and profits	0.2
Total	3.5

Table 4.1 – Economic Factors and Cost Escalation (Arena, 31)

The evaluation conducted by Mark Arena in RAND MG-696 sought to determine the impact of economic and customer driven factors in the on Cost Escalation of Aircraft systems since the 1970s. Overall, his research found that the relative impact of economic factors has been on par with inflation while customer driven factors, including increased design complexity have resulted in cost escalation of up to 9% on average.

Aircraft Type	Average Annual Rate, %
Patrol	11.6
Cargo	10.8
Trainer	9.1
Bomber	8.4
Attack	8.3
Fighter	7.6
Electronic	6.7

Inflation Index	Average Inflation Rate, %
CPI	4.3
DoD procurement deflator	3.8
GDP deflator	3.7

Table 4.2 – Aircraft Type and Cost Escalation (Arena, 11)

Percentage Contributions to Annual Escalation Rate

Comparison	Economy-Driven Factors	Customer-Driven Factors	Cost Improvement Correction	Predicted	Actual
F-15A (1975) to F-22A (2005)	3.5	6.4	0.1	10.0	9.9
F/A-18A/B (1983) to F/A-18E/F (2003)	3.1	3.1	0.0	6.2	4.7
B-1B (1984) to B-2A (1993)	3.1	3.5	0.0	6.5	10.7
C-130H (1980) to C-17 (2005)	3.2	7.1	−0.2	10.2	12.8
E-3A (1975) to E-8C (2005)	3.4	2.3	−0.3	5.4	6.0
E-2C (1975) to E-2C (2004)	3.4	1.9	0.0	5.3	6.4
T-34C (1978) to T-6A (2001)	3.3	3.1	0.1	6.5	6.7
T-34C (1978) to T-45TS (2000)	3.3	11.9	0.0	15.2	15.9

Table 4.3 – Percentage Contributions to Annual Escalation Rates (Arena, 54)

4.2 COST GROWTH DATA

Cost Growth is the increase of cost above the baseline estimate for a given acquisition program. The following evaluation of studies conducted to date will seek to determine the amount of cost growth in acquisition programs and identify the trends related to system type, program type, procuring service and other factors.

In RAND MR-291, "An Analysis of Weapons System Cost Growth," Jeffrey Drezner evaluates a dataset composed of 197 acquisition programs from 1960 to 1990. The database, compiled from Selected Acquisition Reports (SAR), was adjusted for inflation and quantity changes. While inflation has historically increased, quantity changes can either increase or reduce the overall apparent cost growth of the program. If the DoD decides to procure more of a given system then the increased quantity will increase the overall cost of the program while reducing the per unit cost, however if the decision is made to reduce the number of units procured then the overall program cost will be reduced while the per unit cost is increased. In the analysis of the data, Drezner shows the effects of the adjustment for inflation and quantity by providing values for average growth with and without the adjustment. Drezner's research shows a significant impact in the average cost growth over the course of the programs evaluated results from both inflation and quantity change (Table 4.4). In compiling the report Drezner evaluated several other factors which may potentially influence Cost Growth in Programs most notable are the procuring body (Army, Navy, Air Force …), the type of system, whether prototyping was used, mod vs new development and whether the program was joint or teamed. The results of the analysis are shown in Tables 4.5, and 4.6.

	Cost Growth Factor	Number of Observations
Unadjusted	1.71	125
Adjusted for:		
Inflation	1.35	125
Quantity	1.29	125
Further sorts by:		
Maturity	1.30	107
Program size	1.20	107

NOTE: Adjustments are cumulative and inclusive. Data from SARs as of December 1988.

Table 4.4 – Development Costs Growth (Drezner, 22)

The Results for each category show distributions significant enough for discussion. Data evaluated by Service shows the Army with the largest Cost Growth and the Navy with the Smallest. Coincidently the Navy also had the most programs from the sample while the army had the least. The trend could exist because the Army is less experienced at managing procurement or because the smaller average program size is more sensitive to changes in cost. Cost growth by system type also shows interesting results. In this data set vehicles had the highest cost growth at 71% while aircraft, helicopters and spacecraft were relatively lower at 28, 13 and 16% each.

Differences Between Services

Service	Cost Growth Factor	Number of Observations	Average Program Cost (billions FY90$)	Average Age (years past EMD)
Total DE	1.20	120	5.5	9.4
Air Force	1.20	41	6.7	8.7
Army	1.35	28	2.7	10.3
Navy	1.16	51	6.1	9.5

NOTE: DE baseline, weighted average, mature programs.

Cost Growth by System Type

Weapon Type	Cost Growth Factor	Number of Observations	Average Program Cost (billions FY90$)	Average Age (years past EMD)
Aircraft	1.28	14	13.8	10.5
Helicopter	1.13	5	8.1	13.0
Missile	1.17	44	5.1	9.5
Electronic	1.24	27	2.2	8.5
Munition	1.22	7	1.7	7.7
Vehicle	1.71	3	3.0	12.0
Space	1.16	3	2.0	12.0
Ship	1.10	14	7.5	9.1
Other	0.99	3	3.0	5.7

NOTE: DE baseline, weighted average, mature programs.

Table 4.5 – Cost Growth by Service and System Type (Drezner 26, 28)

The Cost Growth data for Prototyping vs Non-Prototyping programs initially appears to be somewhat counterintuitive; however Drezner explains this by pointing out that programs which build prototypes are also more likely to have increased technical uncertainty and risk which could lead to increased cost growth. The data for modification vs new start programs, on the other hand, is directly in line with expectations. Modification or upgrade programs should be low risk and therefore exhibit lower cost growth. The data on single vs joint programs also appears interesting because one might believe that the cost growth could be higher on programs requiring two layers of procurement, however from the data evaluated this is not the case. The results could also be misleading due to the small number of joint programs available for comparison.

The data may be more significant if one could be assured that the programs compared were also similar in nature.

Prototype Versus Nonprototype Programs

	Cost Growth Factor	Number of Observations	Average Program Cost (billions, FY90$)	Average Age (years past EMD)
All programs				
Prototype	1.26	52	4.5	9.7
Nonprototype	1.16	49	7.5	9.1
Higher confidence				
Prototype	1.29	30	4.7	10.7
Nonprototype	1.19	30	8.8	9.8

NOTE: DE baseline, weighted average, mature programs.

Modifications Versus New Programs

	Cost Growth Factor	Number of Observations	Average Program Cost (billions, FY90$)	Average Age (years past EMD)
Modification	1.16	36	4.0	8.9
New start	1.21	84	6.1	9.7

NOTE: DE baseline, weighted average, mature programs.

Single Versus Joint Contracting

	Cost Growth Factor	Number of Observations	Average Program Cost (billions, FY90$)	Average Age (years past EMD)
Single	1.20	112	5.5	9.5
Joint	1.11	8	4.9	6.8

NOTE: DE baseline, weighted average, mature programs.

Table 4.6 – Cost Growth for Prototyping vs Non-Prototyping, Mod vs New and Single vs Joint Programs (Drezner 38, 39, 45)

The Cost Growth Data compiled by Jeffrey Drezner in RAND MR-291 shows an overall average unadjusted cost growth factor of 71% and adjusted average cost growth factor of 20%. The study, published in 1993, evaluates cost data compiled from the SAR reports for 197 programs from the period of 1960 to 1990. The overall analysis of this data shows that trends exist for System Type, Program Type, and procuring body as well as factors such as joint acquisition and prototyping.

4.3 COST GROWTH AND ESCALATION

In 2007, Obaid Younossi and Mark Arena re-evaluate the issue of cost growth in RAND MG-588 "Is Weapons System Cost Growth Increasing." The overall intent of their work was to evaluate data for a smaller quantity of completed military acquisition programs in order to evaluate cost growth in DoD Acquisition Programs and determine if a trend for cost growth exists over the last three decades. The research evaluates data for a set of both completed and ongoing programs. In the first phase of the research, data is evaluated to determine cost growth factors for completed programs. This data is then used to establish trends for cost growth and compared to the cost growth of ongoing programs. In addition, a trend for cost growth in programs over the past three decades is evaluated by normalizing the cost growth per decade, 1970 to 1990, by the relative mix of program types per decade. The following evaluation will seek to compare Younossi's findings for cost growth to those of Drezner as well as to the Cost Escalation Analysis conducted by Mark Arena in RAND MG-696.

In Chapter 2 of RAND MG-588 Younossi presents findings from a cost growth analysis of completed government acquisition programs in order to evaluate trends overall as well as with respect to system type. In evaluating the overall cost growth for completed programs Younossi and Arena determined that the average adjusted Cost Growth was 46% and 65% unadjusted (Table 4.7) (Younossi-588, 16). This represents a somewhat narrower range than that found by Drezner's analysis which showed 71%

unadjusted cost growth and 20% adjusted (Table 4.4 & 4.5) (Drezner 22, 26). The reasons for the disparity can be attributed to the timeframe over which the data sets were compiled as well as the differences in the number of total data points – 46 for Younossi vs 197 for Drezner). In addition, it's been noted that the average values for the data set will also be influenced by outliers in the data. Younossi notes that the overall distribution of cost growth observed in the data set is Log Normal with the bulk of the growth in the range of 0 to 50% (Figure 4.1) (Younossi-588, 16). Overall, the data compiled by Younossi and Arena are comparable to that compiled by Drezner for Average Cost Growth.

CGF Summary Statistics by Funding Categories at MS B

Category	Observations	Mean	Median	Standard Deviation	Min.	Max.
Total (adjusted)	46	1.46	1.44	0.38	0.77	2.30
Total (unadjusted)	46	1.65	1.25	1.08	0.37	5.56
Development	46	1.58	1.34	0.79	0.77	5.47
Procurement (adjusted)	44	1.44	1.40	0.42	0.51	2.29
Procurement (unadjusted)	44	1.73	1.30	1.37	0.28	7.28
MILCON	10	1.33	1.11	0.82	0.51	2.87

Table 4.7 – Overall Cost Growth for Completed Programs (Younossi 16)

Beyond just the Overall Cost Growth, Younossi further evaluates the Data Set to determine the trends for specific system types. As expected, after viewing the results compiled by Drezner, the cost growth relative to system type shows a distribution, however the growth for individual system types in this data set is not always the same as that proposed by Drezner. Table 4.8 shows the cost growth data by system type compiled by Younossi, and Table 4.9 shows a comparison of the two data sets side by side. It's immediately obvious that the two data sets are not exactly matched, but it's also notable that the data compiled by Drezner is, on average, lower than that compiled by Younossi. Particularly notable deviations are the values for Space Systems and Helicopters where the data differs by 50% or more. Younossi explains that the primary difference between the evaluation conducted in MG-588 and that conducted in many other Cost Increase studies is the fact that the data is focused on Completed programs where full cost escalation has been realized; he notes that, "Ongoing programs tend to exhibit lower cost growth than do completed ones" (Younossi-588, 6). The Data set used by Drezner consists of 197 programs with initiation dates from 1960 to 1990 using SAR Data up to 1990. Therefore, the averages derived from the data set used by Drezner are skewed by young programs. This can be further observed in Figure 4.4, where Drezner notes that the average growth for "Mature Programs" is 10% higher than the overall average of 20% found in Table 4.5.

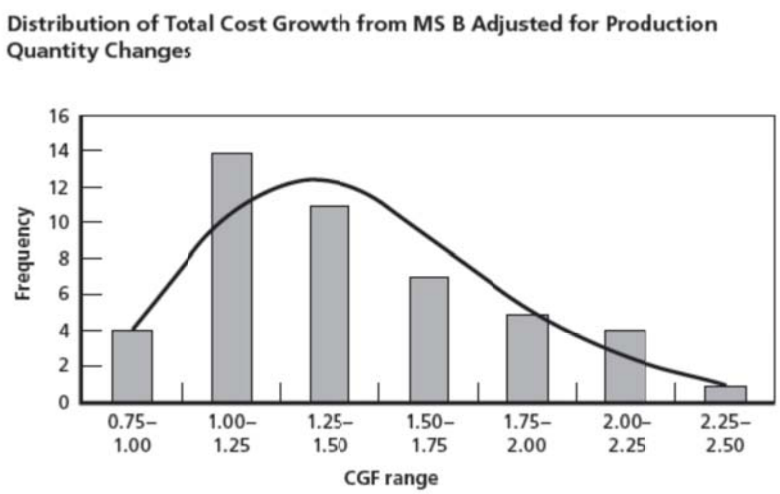

Figure 4.1 –Cost Growth for Completed Programs (Younossi 16)

CGF for Adjusted Total Cost by Commodity Class at MS B

Commodity	Mean	Standard Deviation	Observations
Aircraft	1.35	0.24	9
Cruise missiles	1.64	0.40	4
Electronic aircraft	1.52	0.47	5
Electronics	1.23	0.33	12
Helicopters	1.76	0.21	3
Launch vehicles	2.30	N/A	1
Missiles	1.52	0.38	8
Other	1.40	N/A	1
Satellites	1.55	0.57	2
Vehicles	1.67	N/A	1
Weighted average	1.46	0.38	—
Total observations			46

Table 4.8 –Cost Growth Factor by System Type (Younossi 17)

System Type	Cost Growth Data			
	Drezner		Younossi	
	CGF	n	CGF	n
Aircraft	1.28	14	1.35	9
Helicopter	1.13	5	1.76	3
Missile	1.17	44	1.52	8
Cruise Missile	-	-	1.64	4
Electronic	1.24	27	1.23	12
Electronic Aircraft	-	-	1.52	5
Munition	1.22	7	-	-
Vehicle	1.71	3	1.67	1
Space	1.16	3	-	-
Launch Vehicles	-	-	2.30	1
Satellites	-	-	1.55	2
Ship	1.10	14	-	-
Other	0.99	3	1.40	1
Source	RAND MR-291		RAND MG-588	

Table 4.9 – Cost Growth Factor Data Comparison

Based on the trends derived from the analysis of completed programs Younossi then extends the analysis to evaluate the performance of ongoing programs with respect to those trends. As an example, Figure 4.2 shows a comparison of the average cost growth for completed programs to the cost growth figures for ongoing aircraft programs based on years past Mile Stone B. Notable data points include low risk upgrade programs such as the C-5 RERP and the F/A-18 E/F which are well below the line, and high risk unmanned and tilt-rotor programs such as the Global Hawk and V-22 Osprey which are well above the line. Also noteworthy are the JSF and F/A-22 Fighter aircraft programs which are located right on the line. One could infer from this distribution that the fighter aircraft programs are at the average level of technological risk for aircraft development.

Younossi and Arena were able to show a significant trend for average cost growth of DoD acquisition programs however the primary goal of the research is to determine if the overall average cost growth of programs is increasing over time; essentially an escalation of cost growth. As previously discussed, in RAND MG-696 Mark Arena evaluated the escalation of aircraft cost due to economic and customer driven factors and determined that the average cost escalation of specific platform types ranged from 7 to 12% since the 1970s. In RAND MG-588, Obaid Younossi and Mark Arena evaluate the escalation of Development Cost Growth over a three decade period spanning the 70s through the 90s to determine if a trend exists.

In order to compare the data by decade Younossi and Arena normalize the cost growth data for each decade against a baseline according to the mix of program types. In order to improve the results of the analysis the data set was increased in size and then divided into three subgroupings of systems with similar cost growth or characteristics. In order to expand the data set 33 additional ongoing programs were added to the original set of 46 completed programs. In order to ensure the quality of the data these programs were required to be at least 5 years past MS B as of the December 2004 SAR Report. Three subgroupings of program types were formed in order to account for the variability of program distributions during each decade and improve the results of the normalization process. The groups created were Aircraft & Helicopters, Launch Vehicles & Satellites and Missiles, Electronics & Others.

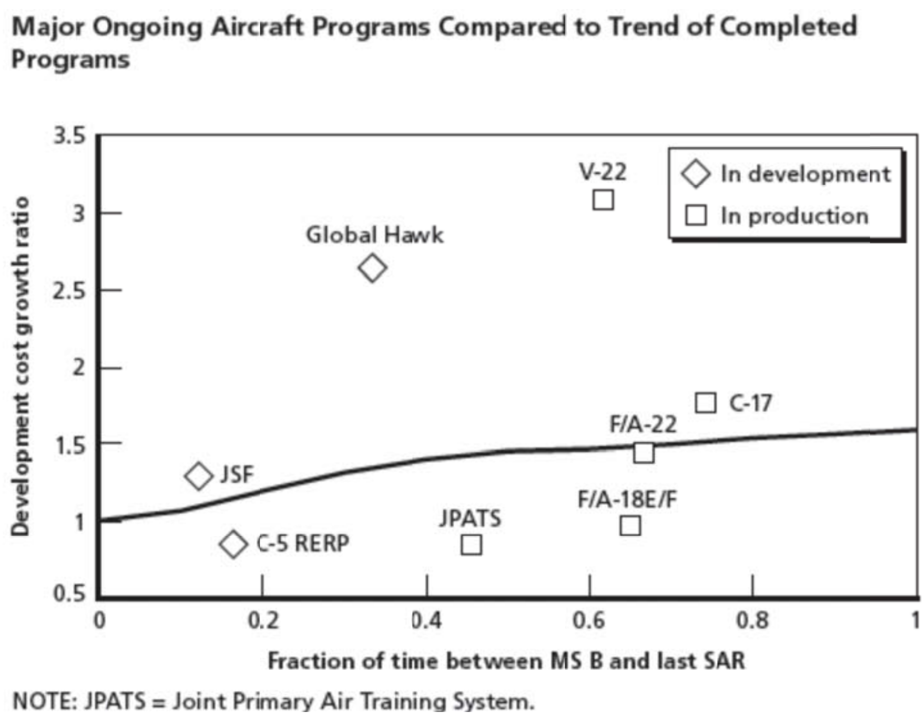

Figure 4.2 –Cost Growth Factor of Ongoing Programs (Younossi 26)

To conduct the normalization process every effort was made to improve the comparability of the data. The total dataset of 79 programs was divided by decade and the Development Cost Growth Factor (DCGF) was then determined for completed programs only, completed programs at 5 years past MS B and for the combined set of completed and ongoing programs at MS B + 5 years. The normalization process was then conducted by scaling the DCGF for each decade using a ratio of program mix from the reference decade (1970 or 1990). The results, detailed in Figure 4.3, show the DCGF for each decade at each phase of the analysis. The most readily noticeable trend in the data is the apparent decrease of the raw DCGF for completed programs by decade (white bars). However, after adding the data for ongoing programs and normalizing the data to the program mix of the 70s or 90s the overall distribution of the DCGF levels off to approximately 1.5 to 1.6 (striped bars). Younossi notes that, "The apparent decline in cost growth [of the raw data] may be influenced by the inclusion of shorter projects and weapon system classes that typically experience less cost growth" (Younossi-588, 38). In addition Younossi explains that the research has shown that different types of programs will have different quantities of cost growth and the groupings made were the best possible compromise between system similarity and program types during each decade. Other options were considered to provide groupings for this evaluation including service type or total cost but were not pursued.

Overall the data, as presented indicates that there is no significant trend of increase or decrease in average Development Cost Growth over the three decade span from the 70s to the 90s. The data when normalized by program mix shows a relatively consistent average over run in program budgets and from the results of this study one could almost infer that there is an average level of technical uncertainty in DoD acquisition programs.

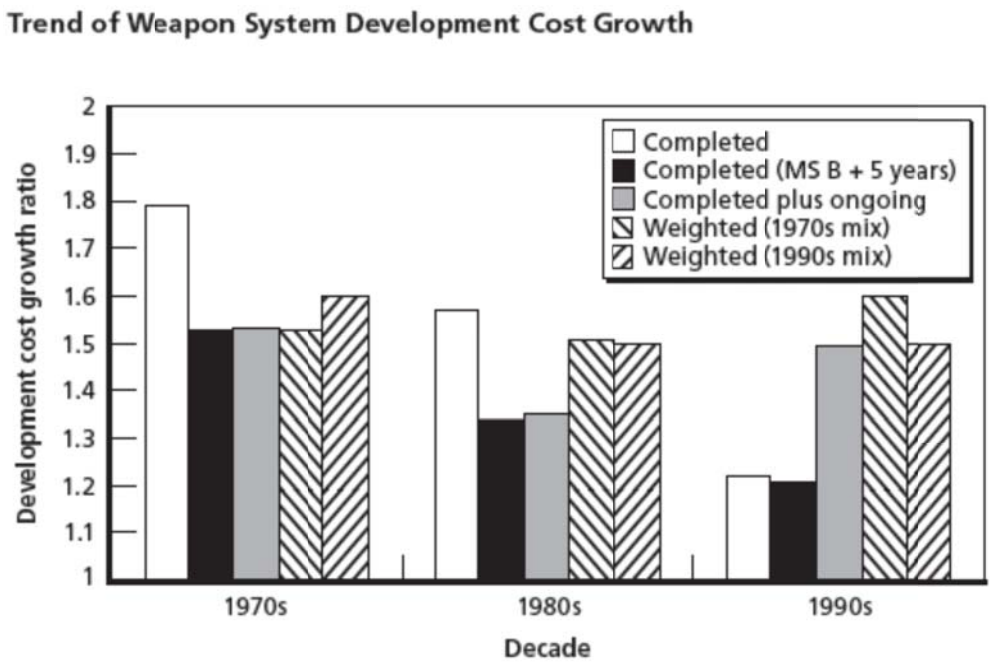

Figure 4.3 – Development Cost Growth Factor by Decade (Younossi 37)

Obaid Younossi and Mark Arena re-evaluate the issue of cost growth in RAND MG-588 with the intent of evaluating data for a smaller quantity of completed acquisition programs in order to evaluate cost growth in DoD Acquisition Programs and determine if a trend for cost growth exists over the last three decades. The research conducted reveals cost growth trends that are generally higher than those documented in previous research conducted by Drezner in RAND MR-291 primarily because of the focus on completed programs. In addition the research conducted showed that the overall average escalation of cost growth has been negligible over the three decade period spanning the 70s through the 90s. Further, this result is not in direct conflict with the conclusions made by Arena in RAND MG-696 which sought to show that the average cost of systems types has increased. The data presented by Younossi and Arena only indicates that the Average Cost Growth of Programs relative to the baseline at MS B has not increased.

4.4 CAUSES OF COST GROWTH

Based on the Evaluation of Cost Growth conducted to this point it's clear that trends exist for Cost Growth relative to System Type, Program Type, Service and several other factors. Similar to the Cost Escalation Trends across programs, Cost Escalation within individual programs can likewise be attributed to several different factors. The following evaluation will seek to reveal some of the factors which contribute to the cost growth of DoD acquisition programs some of which include system type, system complexity, estimating errors, planning errors, requirements changes, prototyping and quantity changes.

In RAND MG-670, "Sources of Weapons System Cost Growth," Joseph Bolten evaluated Contractor reported data on 35 different programs with the goal of identifying the underlying causes of the cost growth reported. The data used for the analysis was compiled from Selected Acquisition Reports (SAR) filed by the contractors and classified into Cost Growth Categories of Estimating and Planning Errors, Decisions, Financial and Miscellaneous. In evaluating the results of the study Bolton notes that the cost allocation strategies utilized are not perfect and that the primary limitation in these analyses is the quality of the initial SAR data (Bolton, 46). It should also be noted though, that Bolten does not normalize the data set for quantity changes, because the growth due to these changes is still realized. The evaluation sought to determine the primary drivers of cost growth across the entire 35 program sample and then determine the differences, if any, which exist based on system type and phase of acquisition (Development and Procurement). In addition, data related to specific programs is also provided for review.

Based on the analysis the primary contributors to cost growth within programs can be attributed to cost estimating errors and requirements growth, which he states, "Account for more than half the total growth" (Bolton, 46). Overall though, he states that largest individual contributor to cost growth in many cases is decisions noting that, "Changes in requirements and in quantity and production schedule are the dominant causes of cost growth" (Bolton, 50). The results for all 35 Programs are shown in Table 4.10 and the results for Overall Cost Growth by System Type are shown in Table 4.11. From the data presented one will note that the overall cost growth reported for all 35 programs totals 60% while the Overall Cost Growth for Aircraft and Helicopters totals 74%. One can also note that the bulk of this difference is the almost 19% increase in Errors related to cost and schedule estimates and technical issues. In addition, from the Decisions category, the primary driver for Aircraft and Helicopters is Requirements and Schedule changes, whereas for the overall average Quantity Change is a much larger driver of cost growth (13% vs 22%). From this data set one can also observe how each factor influences the overall cost growth of a system. Errors in cost and schedule estimates and technical errors impact both the Development and Procurement Cost of a System while the decision to change quantity primarily affects the unit cost of a system and therefore, primarily impacts the procurement phase of a program.

The Development Cost Growth Results for a subset of aircraft development programs are shown in Table 4.12, where it can be seen that, with the exception of the F18 E/F upgrade, all of the listed programs were at minimum 12% over the projected cost. Another notable point here is that the cost growth over estimate does not discriminate between upgrades and new programs. It can be seen that while the F18 upgrade came in just under budget, the Longbow Apache upgrade was almost 100% over budget.

Cost Growth, by RAND Category (mean for 35 mature programs)

Category	Development Cost Growth (%)	Procurement Cost Growth (%)	Total Cost Growth (%)
Errors	19.6	14.7	14.6
Cost estimate	18.0	8.4	10.1
Schedule estimate	1.0	0.9	0.9
Technical issues	0.6	5.4	3.5
Decisions	30.7	57.4	41.6
Requirements	17.5	9.5	12.9
Affordability	−1.9	−0.5	−1.3
Quantity	4.3	40.8	21.9
Schedule	6.0	10.0	8.9
Inter- or intraprogram transfers	4.8	−2.4	−0.7
Financial	1.0	1.8	1.4
Exchange rate	0.1	0.1	0.1
Inflation	0.9	1.7	1.3
Miscellaneous	5.2	1.4	2.4
Error correction	−0.5	−0.3	−0.4
Unidentified	−0.3	−0.3	−0.4
External events	6.0	2.1	3.1
Total	56.5	75.4	60.0

Table 4.10 – Overall Cost Growth Factors (Bolten xvii)

Total Cost Growth, by Program Type (mean percentage)

Category	Aircraft and Helicopters (10)	Missiles (6)	Electronics (13)
Errors	33.7	14.1	1.0
Cost estimate	26.7	14.7	–2.8
Schedule estimate	0.1	0.6	1.4
Technical issues	7.0	–1.1	2.4
Decisions	38.4	29.6	26.4
Requirements	19.0	12.6	6.6
Affordability	–2.5	0.0	–0.5
Quantity	8.4	3.3	17.6
Schedule changes	11.6	13.5	5.9
Inter- or intraprogram transfers	2.0	0.2	–3.2
Financial	1.6	0.8	1.5
Exchange rate	0.4	0.0	0.0
Inflation	1.1	0.8	1.5
Miscellaneous	–0.2	–0.7	–1.5
Error correction	–0.2	0.0	–0.8
Unidentified	0.0	–0.7	–0.6
External events	0.0	0.0	0.0
Total	73.5	43.9	27.5

Table 4.11 – Overall Cost Growth Factors by Program Type (Bolten 43)

Percentage Growth in Development Cost							
RAND MG670 - Table A3 - Pg 62							
Values (%) unless indicated	B-IB	C-17	E-6A	F/A-18E/F	F-22	Longbow Apache A/F	OH-58D
Baseline Development Cost Estimate (mil $)	4,904.1	5,562.6	517.6	6,569.3	22,078.0	427.2	379.4
Development cost growth (mil $)	1,542.4	4,292.3	63.1	-118.7	10,572.4	420.7	49.7
(%)	**31.5**	**77.2**	**12.2**	**-1.8**	**47.9**	**98.5**	**13.1**
Breakdown							
Errors	17.1	30.5	9.4	-2.7	16.7	56.8	-4.0
Cost estimate	17.0	29.0	8.5	-2.7	16.7	56.0	-4.0
Schedule estimate	0.0	1.5	0.0	0.0	0.0	0.0	0.0
Technical issues	0.1	0.0	0.9	0.0	0.0	0.8	0.0
Decisions	13.4	49.1	2.8	0.0	28.9	44.1	16.8
Requirements	17.9	16.0	0.0	0.0	3.2	48.3	19.2
Affordability	-9.9	4.0	0.0	0.2	-1.2	-4.2	-1.0
Quantity	0.0	0.0	2.8	0.0	-6.8	0.0	0.0
Schedule changes	0.0	12.3	0.0	0.0	21.0	0.0	-1.3
Inter- or intraprogram transfers	5.4	16.8	0.0	-0.2	12.7	0.0	0.0
Financial	0.9	-2.5	0.0	0.9	2.3	-2.4	0.3
Exchange rate	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inflation	0.9	-2.5	0.0	0.9	2.3	-2.4	0.3
Miscellaneous	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Error correction	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	0.0	0.0	0.0	0.0	0.0	0.0	0.0
External events	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.12 – Percent Increase in Development Cost Growth for Sample A/C Programs

In AIAA 2009-5436 “Developing Programs on Budget and on Schedule – Part 1,” Glenn Havskjold evaluates the cost growth of Rocket Engine Development Programs for various launch vehicles. In his evaluation Havskjold presents a cause and effect relationship between technical uncertainty and the quantity of rework cycles required to produce a product which meets customer requirements. Havskjold then proceeds to evaluate four specific rocket engine development programs providing a wealth of data on the nature of “Development by Test” noting that within the programs discussed, approximately 73% of the total budget was used to eliminate failure modes while a meager 2% of the total budget was used for the initial design (Havskjold, 6). He attributes the disproportionate amount of work required to fix problems discovered during testing to a failure to correctly ascertain the situation and recognize the quantity of unknowns (read "Errors in Estimating"). It should be noted that the rocket engines evaluated by Havskjold are very complex machines, a factor which contributes to the relative increase in technical unknowns. Figure 4.4 shows the distribution of cost over the programs discussed as well as a "Modified Development Diagram" which shows the nature of the Develop by Test Cycle. Overall, the research conducted by Havskjold attributes the primary cause of cost overruns at the product level to the quantity of technical uncertainty in a given system.

Corrective Actions Largest Development Cost	
Initial Design	2 percent
Engineering	15 percent
Demonstration	10 percent
Corrective actions during full scale test phase	73 percent

Reference 9

Development Costs By Discipline Over Program	
Engineering and management	25 percent
Test	20 - 25 percent
Hardware	50 - 55 percent

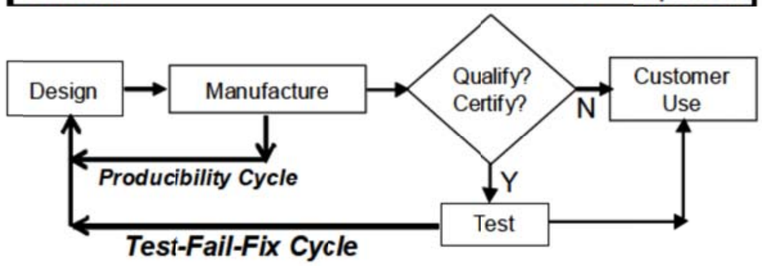

Figure 4.4 – Development Costs and Development by Test Cycle (Havskjold, 6-7)

Cost Increases in Aircraft Development Programs can be classified as Cost Escalation which can be defined as increases over time program to program and Cost Growth which can be defined as cost increases of the baseline estimates within individual programs.

The preceding discussion has shown that Cost Escalation between programs is attributable to both relative economic growth as well as increased customer requirements for fielded systems. The evaluation, based on the work of Mark Arena, showed that the increase due to economic factors including manpower, materials and equipment was approximately 3.5% on average which is on par with the current rate of inflation. Customer Driven Factors including increased capability and increased technical complexity were also evaluated and shown to contribute an average of 3 to 9% depending on the type of aircraft evaluated.

Cost Growth in acquisition is a very large topic and as such it was divided to focus on the evaluations of data, the escalation of cost growth and the causes. The evaluation of data, based on the work of Jeffrey Drezner showed that a significant amount of the Cost Growth reported in Acquisition Programs was attributable to inflation and Quantity Changes. Notably the average unadjusted cost growth in the programs evaluated was 71% whereas the average cost growth after adjustment for inflation and quantity change was 20%. In addition, the data revealed variations in cost growth for programs based on the system type, program type (modification vs new development), the procuring body (Army, Navy …), Prototyping (Yes or No) and Acquisition Strategy (Single or Joint Contractors).

Cost Growth Escalation was evaluated based on the work of Obaid Younossi and Mark Arena. The evaluation conducted used a data set of completed programs to establish a baseline for cost growth since the 1970s in order to evaluate the performance of ongoing programs relative to the baseline as well as to evaluate the escalation of cost growth over the three decade period from the 1970s to the 1990s. The results of the baseline evaluation showed differences when compared to the earlier work of Drezner, however it’s noted that this is primarily due to the focus on completed programs which have higher overall cost growth as well as the smaller sample size used by Younossi. The additional evaluation conducted to compare ongoing programs to the data compiled on completed programs showed that there is a distribution of programs both above and below the previously established average cost growth baseline. Intuitively, and in line with the previous findings of Drezner, the data indicated that relatively high risk programs showed growth higher than average while low risk mod programs generally showed growth less than the average. The escalation of Cost Growth was also evaluated to determine if an increasing or decreasing trend exists in cost growth over time. The evaluation was conducted by expanding the initial data set to include relatively mature ongoing programs and using a normalization process to compare the average cost growth of the data set by decade. Overall, the results show a decreasing trend in cost growth by decade for completed programs; however after including ongoing programs and normalizing by program mix it's shown that the trend in average cost growth is relatively flat over time.

Causes of Cost Growth were evaluated based on the work of Joseph Bolten and Glenn Havskjold. Bolten's work evaluated the SAR Reports of 35 major programs and classifies the reported cost growth into categories of Errors, Decisions, Financial and Miscellaneous. The evaluation conducted reveals that the primary drivers of cost growth in the programs evaluated are due to errors in initial estimates and technical issues as well as requirements and quantity decisions. Glenn Havskjold evaluates cost growth for high technology rocket engines based on the quantity of rework cycles required to complete the project with the goal of identifying a relationship between technical uncertainty and the quantity of rework cycles required. Overall, he attributes the primary cause of cost growth in the systems evaluated to the level of technical uncertainty going into the program.

Based on the preceding evaluation one can ascertain that on average there is a consistent trend of cost growth in acquisition programs that results primarily from inadequate estimates at the contractor level and changes in system and quantity requirements at the government level.

5.0 Nunn McCurdy

The Nunn-McCurdy process was initiated in 1982 and requires the DoD to notify Congress in the event that a defense acquisition program exceeds specific thresholds with the purpose of improving visibility and oversight of Defense Acquisition Programs at the congressional and DoD levels.

Under the current policy Nunn-McCurdy breaches are defined under categories of significant and critical. Quoting the Government Accountability Office (GAO), "A breach of the significant cost growth threshold occurs when the program acquisition unit cost or the procurement unit cost increases by at least 15 percent over the current baseline estimate or at least 30 percent over the original baseline estimate. A breach of the critical cost growth threshold occurs when the program acquisition unit cost or the procurement unit cost increases by at least 25 percent over the current baseline estimate or at least 50 percent over the original baseline estimate" (GAO-295, 3)

Recent Revisions to the Policy include the National Defense Authorization Act for Fiscal Year 2006, which requires thresholds for Nunn-McCurdy breaches to be measured against the program initial baseline, and the Weapon Systems Acquisition Reform Act of 2009 which requires the secretary of defense to terminate a program that experiences a critical breach unless a written certification is submitted to congress. Baseline estimates can still be modified under current DoD policy, however requiring contracts to be judged against the initial baseline prevents the DoD from avoiding a breach by re-baselining the program (GAO-295, 3). Forcing the secretary of defense to submit a written certification for programs experiencing a critical breach imposes a formal review process for program justification. Quoting the GAO:

Programs with critical breaches must be terminated unless the Secretary of Defense certifies that

- continuation of the program is essential to national security,

- there are no alternatives to the program providing acceptable capability to meet the joint military requirement at less cost, the program's

- new estimates for program acquisition unit cost or procurement unit cost are reasonable,

- the program is higher priority than other programs whose funding must be reduced to accommodate the growth in cost of the program, and

- the program's management structure is adequate to manage and control program acquisition unit cost or procurement unit cost."

… If the program is not terminated, the Secretary of Defense must (1) restructure the program to address the root causes of the cost growth; (2) rescind the most recent milestone or key decision point approval and withdraw any associated certification; (3) require a new milestone or key decision point approval before taking certain contracting actions to ensure that the program can be restructured without unnecessarily wasting resources; (4) report on all funding changes made as a result of the growth in cost of the program, including reductions made in funding for other programs to accommodate the cost growth; and (5) conduct regular reviews of the program.

5.1 TRENDS IN NUNN-MCCURDY BREACHES

Several Trends have been observed in the Nunn-McCurdy process between 1997 and 2009 as evaluated in GAO Report GAO-11-295R "Trends in Nunn-McCurdy Cost Breaches for Major Defense Acquisition Programs."

Overall, during the time period from 1997 to 2009, a total of 74 Nunn-McCurdy breaches were reported for 47 major defense acquisition programs. Based on an evaluation of the data it was observed that by service the Air Force had the largest number of breaches, by Program type aircraft and helicopters had the highest quantity of breaches (32 Total, 64% Overall) and of the 47 programs with breaches 18 of these programs had breached more than once.

Figure 5.1 shows the quantity of breaches per year from 1997 to 2009, Figure 5.2 shows the quantity of breaches by service and Table 5.1 shows the quantity of breaches for each program type.

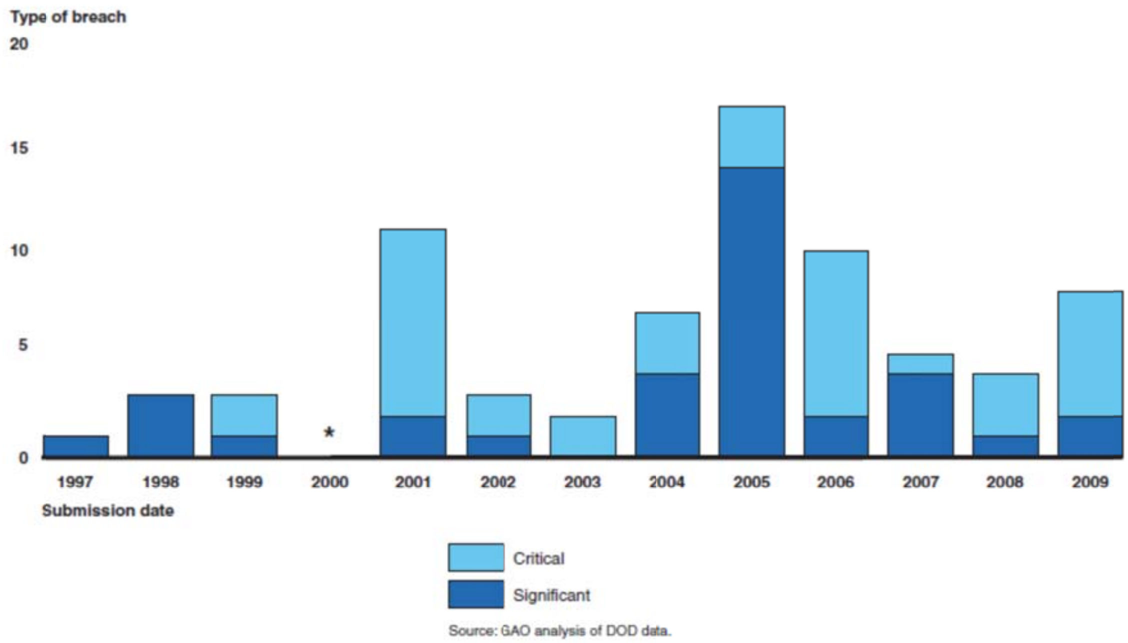

Figure 5.1 – Crtical and Significant Breaches by Calendar Year (GAO-11-295,

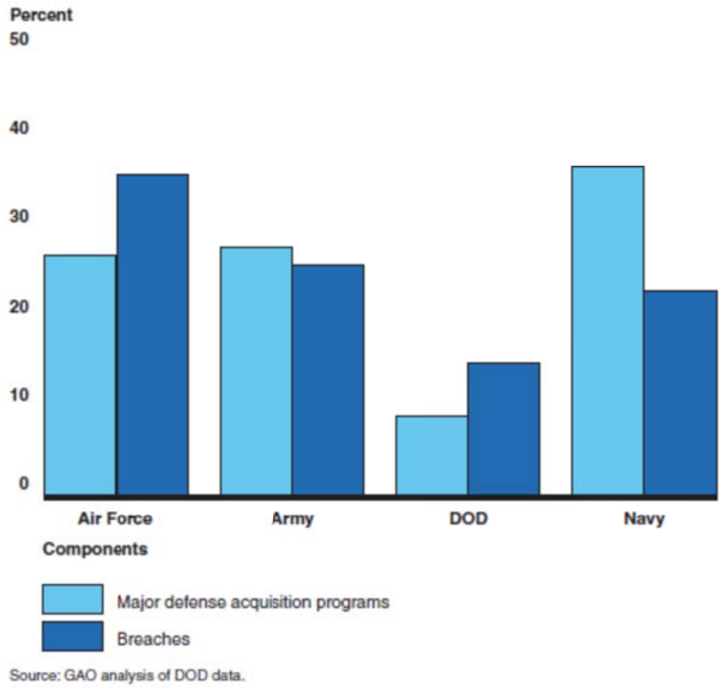

Figure 5.2 – Major Defense Acquisitions and Breaches by Service (GAO-11-295, 8)

Program type	Number of breaches
Aircraft	19
Aircraft (Bomber)	2
Aircraft (Fighter)	5
Aircraft (Other)	4
Aircraft (Transport)	5
Aircraft (Unmanned)	3
Helicopters	13
Satellites	11
Chemical demilitarization programs	7
Munitions	5
Command, control, communications and intelligence	5
Missiles	4
Ships	2
Submarines	3
Ground combat	2
Other[a]	2
Transport vehicles	1

Source: GAO analvsis of DOD data.

Table 5.1 – Breaches by Program Type 1997 to 2009 (GAO-11-295, 10)

5.2 Factors Responsible

In the data evaluated by Sullivan for breaches occurring between 1997 and 2009 it was determined that Nunn-McCurdy Breaches occur as a result of a variety of factors. Those factors cited as being the most prevalent are Engineering and Design Issues, Schedule Issues and Quantity Changes. Other issues Cited include Revised Estimates, Economic Changes, Requirements Changes, Support Costs, Funding Issues and Production Issues (Figure 5.3).

Aside from Quantity changes which are outside of the control of the contractor, the four primary causes reported are Engineering and Design issues, schedule issues and revised estimates; all of these factors could be interpreted as inadequate systems definition at program inception. In the evaluation the GAO points out that breaches attributed to Engineering and Design issues could result from, “programs started without adequate knowledge about their requirements and the resources needed to fulfill them” (GAO-295, 11). Further, breaches due to Revised Estimates infers that the, “[Original] estimates were based on inaccurate assumptions” (GAO-295, 11). Similar conclusions can be drawn for breaches resulting from schedule issues. Overall the GAO points out that the cost estimated for most defense procurement programs are based on limited knowledge and over-optimistic assumptions. In referencing a 2008 GAO report on the topic of program estimates it’s stated that, ”development costs for major acquisition programs are often underestimated at program initiation—by 30 to 40 percent in some cases—in large part because the estimates are based on limited knowledge and optimistic assumptions about system requirements and critical technologies ” (GAO-295, 11).

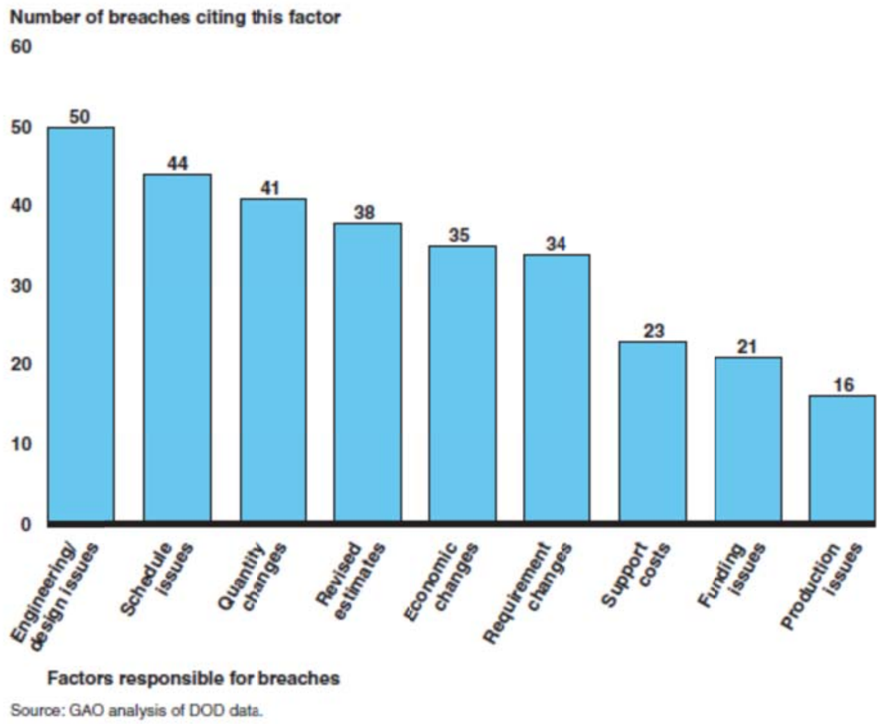

Figure 5.3 – Factors Cited for Breaches 1997 to 2009 (GAO-11-295, 11)

Of the causes cited, customer initiated reasons for costs over runs include Quantity Changes and Requirements Changes. The data presented by the GAO on Nunn-McCurdy breaches due to Customer Imposed factors is in general agreement with the previous evaluations on causes for cost increases during program development where it was shown that quantity changes could have a very significant effect on development cost increase.

Overall the data presented by the GAO is also in general agreement with the results of the previous analysis on cost increase overall. It should be noted that the causal data presented on Nunn-McCurdy breaches is organized by occurrence whereas the data in the previous evaluation was organized by overall impact on cost growth.

5.3 FUTURE POLICY

Going forward the DoD is instituting processes to provide early warning that programs are in trouble and is refining the policy to limit the number of breaches caused by quantity change. The GAO states that:

> DOD has instituted a process to provide earlier warning of potential breaches and plans to propose changes to try to limit the effect of breaches caused by quantity changes. Specifically, the Joint Staff has implemented a Nunn-McCurdy trip wire process to evaluate the factors that are contributing to cost growth so that programs can take mitigating actions. Our analysis shows nearly 40 percent of Nunn-McCurdy breaches occurred after a production decision had been made—when a program has fewer options for restructuring. DOD also plans to propose a legislative amendment to reduce several statutory requirements added in 2009 for Nunn-McCurdy breaches when it determines the breach was caused primarily by quantity changes that were unrelated to poor performance. Tracking changes in research and development costs, which are not sensitive to quantity changes, would be one way DOD could evaluate program performance in this context.

The Nunn-McCurdy process was initiated in 1982 with the purpose of improving visibility and oversight of Defense Acquisition Programs at the congressional and DoD levels. In data evaluated between 1997 and 2009 74 total breaches were reported for 47 programs with 18 programs reporting more than one. An evaluation of the reported breaches revealed trends by service, program type and by cause reported. Based on the available data the Air Force had the largest quantity of breaches, 64% of all breaches were for aircraft programs and engineering and design issues are the primary cause reported for breaches. In addition, it was found that the data generally agrees with previous evaluations on cost increase. Further, changes are being implemented to refine the process and improve oversight.

6.0 Case Studies from Recent Development Programs

In the discussion which follows, case studies from several recent aircraft development programs will be evaluated to determine the factors which influenced the relative success or failure of each. A comparative study between the F/A-18 E/F and F/A-22 Fighter aircraft platforms will be evaluated to highlight the significant contrast in cost growth in these two programs and the VH-71 Presidential Helicopter Program will be evaluated to highlight the danger in assuming that the low risk inherent to modification programs precludes any potential for significant cost growth.

6.1 F-22 Raptor vs F-18 E/F Super Hornet

The Lockheed Martin F-22 is a revolutionary fighter aircraft designed from the outset to replace the McDonald Douglass F-15 in the air superiority role (Younossi-276, 2) while in contrast, the McDonald Douglass (now Boeing) F-18 E/F was developed to increase the capability and survivability of the current F-18 C/D (Younossi-276, 3). As noted in the previous evaluations of Cost Growth upgrade or modification programs typically exhibit lower cost growth than new development however the F-18 E/F and F-22 represent two very significant data points in the development history of fighter aircraft. As noted in Figure 6.1, the cost growth for the F-18 E/F is well below the average cost growth for the fighter aircraft evaluated while, with the exception of the F-14, the F-22 is well above the average. The F/A-18E/F and F/A-22 fighter aircraft programs initiated the EMD phase of development almost simultaneously at the beginning of the 1990s however while the F-18 completed both on Cost and on schedule the F-22 continues to incur schedule slips and cost growth. The following evaluation will seek to determine the factors which have affected the success or failure of each program with the goal of determining what lessons can be employed in future acquisition strategy. Based on the research compiled by Obaid Younossi and David Stem in RAND MG-276, “Lessons Learned from the F/A-22 and F/A-18 E/F Development Programs,” Several factors have influenced the success of the F-18 and the cost growth of the F-22 including Technological Risk, Program & Financial Management Strategy and Work Split & Industrial Base.

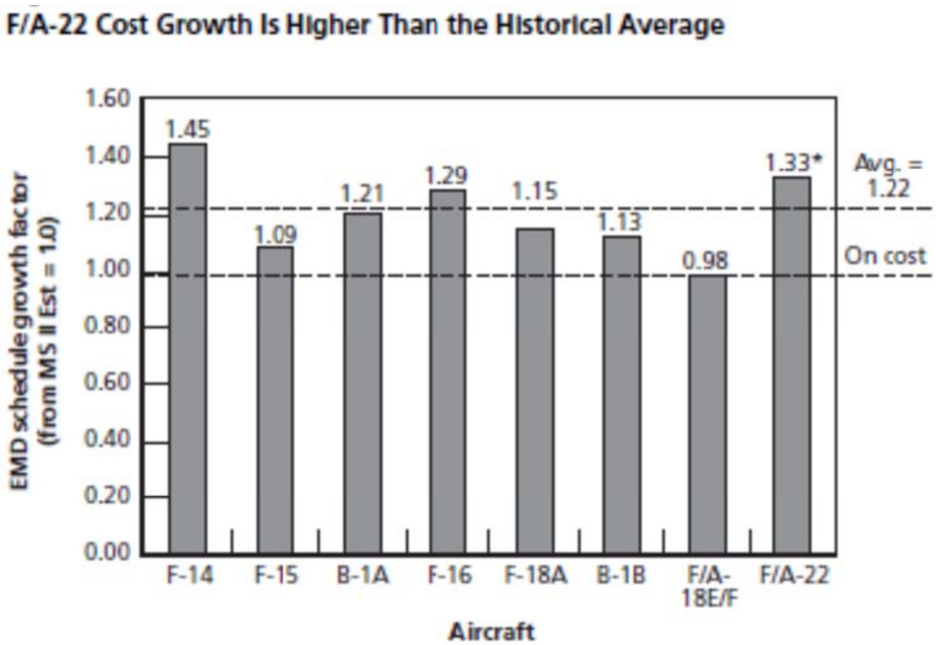

Figure 6.1 – Historical Cost Growth for Fighter Aircraft (Younossi-276, 10)

The most readily obvious difference between the F/A-18 E/F Super hornet and the F/A-22 Raptor is the level of technology employed in each. As noted, the F-18 E/F began as a low risk upgrade to the existing F-18 C/D, while the F-22 development program is a high risk envelope expanding program requiring according to Younossi

> Supercruise capability (the ability to cruise at supersonic speed without afterburner) and engines with vectoring nozzles for short takeoff and landing (STOL) capability and greater agility, combined with stealth and F-15/F-16-class maneuverability. Planners

> decided to require development of the first fully integrated fighter avionics system, and incorporate revolutionary new technologies into the fire control radar based on a solid-state active electronically scanned array (AESA) technology (Younossi-276, 16)

The F-18 E/F upgrade required extensive airframe modifications and new engines however the avionics would be integrated from the C/D model and the new engines would be derivatives based on existing architecture from the F-18 C/D (Younossi-276, 23). Both programs pursued risk mitigation prior to development however the overall results were different. In preparation for the Advanced Technology Fighter (ATF) Program, the concept which became the F-22, the Air Force implemented several risk mitigation development programs to prepare the technology required for the stealth requirements, improved radar, integrated avionics, improved engines and short takeoff and landing (STOL) capability however all of the technology would still need to be integrated into the final product (Younossi-276, 16). In addition, the airframe for the F-22 was developed as the YF-22 and competed in a fly off against the Northrop YF-23 to win the ATF contract. Significant risk mitigation also took place in generating the requirements for the F-18 E/F. In addressing options to meet the requirements the Navy considered several options in addition to the upgraded F-18 including an upgraded F-14 and a Naval Version of the ATF, however according to Younossi, following the cancellation of the A-12 in 1991, “The Navy preferred to pursue the lower-cost, lower-risk multimission design approach based on the Hornet 2000 studies” (Younossi-276, 22). Following the decision to pursue the improved hornet the Navy further directed McDonald Douglass to pursue additional risk mitigation strategies (Younossi-276, 21). In addition, it should also be noted that although the F-18 intended to use the avionics from the C/D model for the initial development several stages of avionics upgrades were planned in the format of an evolutionary acquisition strategy thereby eliminating the risk to the initial development program (Younossi-276, 43). A comparison of Development cost data for each program is shown in Figure 6.2; note the relative difference in cost due to avionics in the initial development programs. Overall, it can be seen from the outset that the F/A-22 program assumed a significantly higher level of technological risk than that pursued by the F/A-18 E/F.

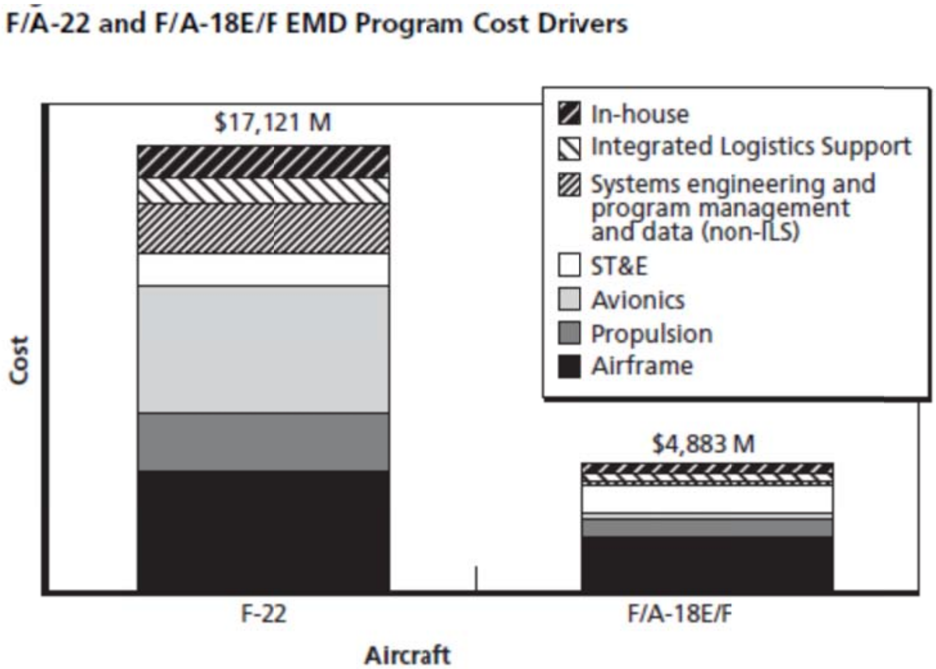

Figure 6.2 – Development Cost Data for the F-22 and F-18 E/F (Younossi-276, 31)

The F-18 and F-22 programs aside from starting almost simultaneously also both employed the new Integrated Product Team (IPT) framework being evaluated by the DoD and both employed the Earned Value Management System (EVMS) for tracking program cost and schedule however one finished on budget while the cost of the other continues to climb. According to Younossi, factors contributing to the relative success of each program can be linked to differences in the manner in which each program implemented these tools. Both programs were pilots for the IPT structure that was being implemented for new programs by the DoD in the early 1990s. Integrated product teams are part of a Matrix Organizational approach to development which integrates product and functional groups. Individual IPTs are composed of a team of individuals representing various engineering and management functions on both the government and industry side (Younossi-276, 17, 26). The F-22 was required to implement the IPT structure during the Dem/Val (now called Technology Development) stage of the program whereas the F-18 instituted the new structure at the inception of EMD. It's noted by Younossi that the implementation of the IPT framework during the ATD program resulted in an almost 2 year delay of the initial fly off while in contrast he also states that, "Many observers believe effective use of the IPT approach was one of the most important management initiatives promoting stability and effective management of technological challenges in the F/A-18E/F effort" (Younossi-276, 17, 26). Both programs also implemented the EVMS process for budget and schedule tracking, but there are clear differences between the budgeting methods employed in each program. EVMS is a tool used by contractors and the government to track cost and schedule performance actuals against the planned baseline. In tracking project performance the contractor reports hours used or and work completed to calculate the Actual Cost of Work Performed (ACWP) and Budgeted Cost of Work Performed (BCWP) for comparison against the Budgeted Cost of Work Scheduled (BCWS). Accurate tracking of EVM data allows the contractor and government to maintain up to date status of the progress of a given program (Younossi-276, 47). According to the research conducted by Younossi the F-22 Program only budgeted 2% for management reserve (MR) while the program managers on the F-18 budgeted 10% for MR. Management reserve is cost factored into the initial estimate in order to address problems in the program as they arise; it's essentially a way to account for unknowns (Younossi-276, 50). As a result of effective planning the MR for the F-18 E/F program lasted all the way through the program whereas the MR for the F-22 was entirely consumed within two calendar years. The F-18 E/F and F-22 programs both employed new strategies for program and financial management however, based on an evaluation of the implementation of these strategies on each program one can argue that effective implementation of both acquisition strategies significantly contributed to the cost and schedule performance of the F-18 E/F.

The third and potentially most significant factor which affected the success of the F-18 and F-22 programs is the Work Split & Industrial Base employed by each program. Per Younossi, the F-22 program implemented an even work split over three contractors in order to preserve the capabilities of each to continue on as prime contractors in the defense industry. Therefore, although Lockheed Martin functioned as the Prime Contractor for the F-22 program the work split divided major systems of the aircraft over three contractors. Younossi argues that the artificial work split for the program resulted in cost over runs and schedule delays because the contractors involved had never formally worked with each other in the past. In addition, the YF-22 technology demonstrator was developed by the Lockheed Martin Skunkworks in Burbank California a team known for its ability to execute on aircraft development programs including the U-2 and SR-71 spy planes and the F-117 A stealth attack aircraft. At the inception of the EMD contract the development and production of the F-22 was moved to the Lockheed Martin facility in Marietta Georgia. Younossi explains that the Marietta facility produced cargo aircraft and was not equipped with engineers who had the expertise required to develop a high performance stealth aircraft. In addition, he notes that less than 10% of the original development team moved to Marietta with the program. He states that

> [Although] Lockheed and the U.S. government publicized the move as a cost-cutting measure ... This inability to attract engineers and managers who gained specialized

experience during the early phase of development from Burbank to Marietta along with Marietta's lack of a design team capable of meeting the F/A-22's engineering challenges arguably may have been the root of many problems during development (Younossi-276, 19-20).

In contrast the F-18 E/F program benefitted from an established work split from the C/D model as well as an established supplier base and production facility. Younossi notes that both McDonald and Northrop, "Had experienced design teams in place and drew heavily from [an] existing supplier and industrial base" (Younossi-276, 24). The advantage provided by existing business relationships and experienced teams on the F-18 is another factor which contributed significantly to the success of the program, and ultimately the opposite lead to cost increase on the F-22.

The preceding evaluation, based on the work of Obaid Younossi, explored several factors which influenced the success of the F-18 E/F program and the cost growth of the F-22. The factors evaluated include Technological Risk, Program & Financial Management Strategy and Work Split & Industrial Base. The F-18 E/F program benefited from low technological risk and evolutionary acquisition strategy, effective implementation of the IPT Program structure, EVMS tracking tools, program budget and established business relationships and engineering teams. In contrast the F-22 program suffered cost growth resulting from a high risk development strategy combined with difficult implementation of the IPT Structure and Inadequate initial Estimates of Management Reserve as well as an un-established work split and industrial base.

6.2 VH-71 Presidential Helicopter

In the previous case it was determined that a strategy focused on the upgrade of an existing platform could be significantly successful given the right mix of program management and risk mitigation. The following case will evaluate another upgrade program which had significant importance to the DoD.

The VH-71 Presidential Helicopter Program, initially designated VXX was initiated following a re-evaluation of Presidential Transportation Requirements following the September 11, 2001 Terrorist attacks on the United States (GAO-380, 2). The program sought to procure a fleet of 23 helicopters to replace the aging fleet of Sikorsky VH-3D and VH-60N Helicopters currently used by the president and other VIPs for transportation in the United States and around the world (Global Security). The contract, awarded in 2005 to a Lockheed Martin led team consisting of Augusta Westland and Bell Helicopter Textron, would modify the Augusta Westland Designed EH-101 Helicopter to meet the requirements for the VXX mission. The aircraft, Designated VH-71 and Marine One when the president is on board, would be delivered in two increments in order to provide Initial Operating Capability (IOC) as soon as 2008. Increment one would provide 5 total aircraft in order to develop IOC capability while increment 2 would be developed to meet all of the VXX mission requirements (Global Security). The initial contract award was valued at $1.7 bil for system development and demonstration but the overall contract was valued at $6.1 bil for all helicopters, test and development efforts. In June of 2009, however, the program was cancelled (from the GAO)

> … following the expenditure of close to $3 billion and a critical Nunn-McCurdy breach of the cost growth threshold, the Department of Defense (DOD) terminated the Navy's VH-71 presidential helicopter acquisition program and contract because of cost growth, schedule delays, and projected system performance (GAO-380, 1)

The following evaluation will seek to determine the causes which led to the cancellation of the VH-71 program with the goal of determining what lessons can be employed in future acquisition strategy.

In a Jan 1, 2005 Article from Aviation Week, Michael Bruno quoted John J. Young Jr., the Assistant Secretary of the Navy for Research Development & Acquisition as saying

> This decision truly reflects the best value and capability for the American taxpayer who is funding it, the Marines who will operate it, and the future presidents who will fly in it

The question then becomes, what went wrong? In a 2011 study conducted by the GAO to evaluate the lessons learned from the VH-71 program it's reported that the overall reasons for cost escalation and subsequent program cancellation can be attributed to three primary causes: High Risk Initial Business Case, Lack of Proper System Definition and Inability to Make Trade-Offs required to meet the Program Budget. Fundamentally, though, all of the reasons cited by the GAO can be classified under the broad heading of Inadequate Planning and Estimating.

The GAO states that the VH-71 program had a High Risk initial Business Case because the program employed a two-phase acquisition process simultaneously initiating production and development efforts under a compressed schedule (GAO 380, 5). Jeremiah Gertler of the Congressional Research Service explains that the program was divided into two phases in order to provide a limited capability initial aircraft for short-term transitional use and a final increment two aircraft meeting all of the mission requirements. He notes that the most significant differences between the increment I and increment II aircraft are the addition of a new engine, transmission, and main rotor blade configuration (Gertler, 4, 7). Gertler further states (quoting the GAO)

> The VH-71 program began with a compressed schedule dictated by White House needs stemming from the September 11, 2001, terrorist attacks. According to the program manager, this aggressive acquisition strategy included a source selection process that was shorter than desired and contributed to confusion regarding specifications between the program office and the contractor and concurrent design, testing, and production that resulted in increased program risk, an unsustainable schedule, and inaccurate cost estimates (Gertler, 8).

Overall it can be observed that in procuring the VH-71 aircraft, significant risk was assumed by the government in order to field a new system as quickly as possible.

Lack of proper systems definition is another fallout from the high risk initial development schedule. Per the GAO, the VH-71 program initiated key phases of the systems engineering review process well after the normally acceptable stages which resulted in disagreement over design requirements and a lack of design stability as the program progressed. It's stated

> Had the VH-71 program followed acquisition best practices and conducted early systems engineering, it could have led to a feasible, stable preliminary design ideally before development start. In turn, a stable, early design allows for more accurate program cost estimates and a better foundation for sufficient funding commitments. Instead, it began without completing systems engineering until well after development start. As a consequence, it never achieved design stability and experienced significant cost and schedule problems in development (GAO-380, 4)

The VH-71 Program System Requirements Review (SRR) should have occurred prior to development start however it was not initiated until 4 months following the initiation of the development stage (GAO 380, 6). Further, the program Preliminary Design Review (PDR) and Critical Design Review (CDR) for both increment 1 and 2 were conducted behind schedule. The GAO points out that the PDR for increment I, which should have been completed prior to the start of development, occurred 13 months after the start of development. Further, "A PDR for Increment 2 had not occurred by the time a stop work order was placed on the Increment 2 effort in December 2007—35 months after the start of Increment 2 development "(GAO 380, 6). In brief, the VH-71 experienced significant problems as direct fallout from a failure to properly execute the systems engineering processes required to ensure that the program was moving forward with a stable configuration and goal. The systems engineering process is a tool for ensuring that proper planning is executed in a timely manner and the failure of the program to properly implement these process is a clear indication of inadequate planning.

In evaluating the causes of failure in the VH-71 program the third cause noted by the GAO is the inability to make trades in the design to in order to meet the programs financial and schedule goals. He clarifies that the inability to make trade-offs was a result of the stringent requirements of the program and states

> Stringent performance requirements (some with no flexibility) were laid out for the system prior to the start of development and did not appear to involve significant consideration of trade-offs of cost, performance, and schedule negotiated between the customer and the developer (GAO 380, 7)

In evaluating these statements one can infer that the fundamental issue again falls back to inadequate planning. If the program had been properly planned from the outset and the necessary requirements reviews conducted the program managers on both sides would have been aware of the conflict which existed between the overall requirements and desired program cost and schedule.

The VH-71 program was initiated following a re-evaluation of Presidential Transportation Requirements following the September 11, 2001 Terrorist attacks on the United States. From the outset the program was intended to be a low-risk modification or upgrade program and at the time of award Lockheed Martin Systems Integration claimed that the, “Program would integrate a "system of systems" with a modern, in-production aircraft to provide the president with safe and reliable helicopter transportation” (Global Security VH-71). However, the failure to properly plan and estimate the effort in conjunction with an accelerated schedule and hard requirements which did not allow for trade-offs to be made between program goals and cost resulted in significant cost growth and schedule delay. At the time of cancellation in 2009, the program was estimated to double in cost from the initial estimate and be delayed by 6 years. The GAO states that, “The VH-71 program’s failure to follow acquisition best practices was a critical factor in the program’s poor performance that led to its ultimate termination,” (GAO 380, 8) and recommends that future programs learn from these mistakes.

In the preceding evaluation of defense acquisition programs it was shown that the F-18 E/F program was incredibly successful because the program was based on a low risk technical strategy and benefited from successful implementation of IPT Program structure and EVMS tracking tools as well as established business relationships and engineering teams. In contrast the F-22 and VH-71 programs both suffered from high cost growth although each program used a different acquisition strategy. The F-22 was a revolutionary clean sheet design implementing the most advanced technologies in the airframe, avionics and engines while the VH-71 was intended to be an upgrade to an existing platform similar to the F-18 E/F. Although there are some differences between the reasons for cost growth in the F-22 and VH-71 programs one will note that both ultimately suffered from inadequate initial estimates and program planning. The F-22 program suffered from inadequate planning of the development budget and work split and the VH-71 program suffered from inadequate planning of program requirements. It could be argued that both of these programs if planned more effectively had the potential to meet cost targets, and that the F-18 E/F program conversely could have suffered the same fate.

7.0 Cost Reduction Recommendations

From the previous evaluation of factors affecting Cost Increase in acquisition programs as well as the case studies from individual programs one can discern that some costs such as those related to producing the actual aircraft must increase as a natural reflection of the economy and growing customer needs while others such as those resulting from poor estimates and changing requirements could be decreased by applying risk mitigation factors up front. As with factors which increase cost, many methods for reducing cost in aircraft programs have also been studied and research in this area has provided many different avenues for evaluation. As noted by Havskjold, the "Concurrent Engineering Body of Knowledge" defines 84 individual areas under "5 Pillars" (Strategy, People, Process, Tools and Technology) (Havskjold, 2) which have been identified as potential avenues for cost reduction in development programs. From the previous evaluation of cost growth, Nunn McCurdy breaches and the case studies on individual aircraft programs several causes for cost increase in aircraft programs have been identified. On the DoD side the primary causes for cost increase stem from requirements and quantity changes. On the contractor side the primary causes identified are errors in evaluating program requirements, errors in estimating the initial program schedule and cost, errors in estimating the technical complexity of the program and inadequate program management. The following evaluation will explain the factors which are outside of the control of the contractor and focus on implementing a framework for system development through systems engineering which can be used to address the factors identified from the previous research which are within the control of the contractor.

7.1 Quantity and Requirements Changes

The current financial climate is not ideal, as noted by Elizabeth Ferrell in the Bureau of National Affairs Federal Contract Report:

> The current FY2011 budget and funding crisis has created serious short- and long-range implications for companies performing contracts for the United States. Our federal government has performed under stop-gap appropriations resolutions for over half of the fiscal year, at flat spending levels that are insufficient to fully perform many ongoing contracts. Moreover, the proposed budgets for the remainder of FY2011 and beyond reflect significant cuts in funding available for procurement. As a result, the government will be forced to take steps to reduce procurement spending by changing, restructuring, or abandoning programs and contracts. Contractors can expect partial or total terminations, de-scoping of quantities and capabilities, contract stretch-outs, breaks in production, and other efforts by the government to alter contracts and programs to align government spending with available funds (Ferrell, 1).

The DoD must constantly align its budget with available funding which fluctuates in response to an ever changing political and economic environment. In addition, the DoD must balance that budget over a number of strategic priorities. In order to manage the conflict between available budget and priorities the DoD and procuring agency will institute quantity and requirements changes in acquisition programs which commonly result in cost growth.

According to the March, 2011 GAO Assessment on Selected Weapons programs, the DoD is currently running 98 Major Defense Acquisition Programs (MDAPs) that are publicly reported (GAO-233, 4). In light of this the DoD will make changes to specific programs by adjusting Quantity and Schedule in order to address budgetary concerns. For example, the production run for the previously discussed F/A-22 Raptor was reduced from an initially proposed quantity of 648 aircraft to 188 total aircraft in order to reduce the overall program cost to meet the initial estimates. Under the original budget the program was projected to cost $80 bil ($22 bil for Development and $58 bil for production) (Arena 63, 67). Following readjustment the final program cost is $77.4 bil ($39.2 bil for Development and $37.6 bil for production) with a unit cost change from

$139 mil to $412 mil per copy (GAO-233 140). This change ultimately allowed the program to stay within budget, however at a significant increase in unit cost. In another example, the entire mission of the C-17 changed reducing the proposed quantity required from 210 to 40 (GAO-26). Although, ultimately 120 C-17 Aircraft were procured, the reduction in quantity ultimately increased the unit cost. Overall, the DoD will adjust quantity in order to maintain a balance between operational requirements and available budget.

Requirements changes instituted by the procuring body are, generally, outside of the control of the contractor. There are numerous examples of requirements changes or "requirements creep" in aircraft development programs. For example, the Global Hawk UAV program developed a second aircraft to meet revised sensor payload requirements (GAO-222) and in order to further justify the F-22, the Air Force added the attack role to the F-22 making it the F/A-22 in order to align the program with perceived mission requirements following the dissolution of the Soviet Union (Younossi-588, 2). Each of these changes in program requirements significantly affect the overall cost of the program in some way which can result in adverse cost performance outside of the direct control of the contractor.

Ferrell points out that the DoD budget is continuing to experience reductions in order to meet goals in other areas of the government. She notes that for 2011 the DoD has only received $513 bil of the $549 bil requested to fund programs and that further budget cuts are expected in order to achieve "President Obama's goal of achieving $400 billion in defense spending savings by 2023" (Ferrell 2). She states

> Given the budget crisis for FY2011 and the foreseeable future, agencies simply will have insufficient funds with which to execute existing and planned programs. Agencies will be forced to take drastic action to align procurement expenditures with available funding. Historically, agencies have employed a variety of measures to cope with inadequate

> funding, including reducing capabilities or quantities (de-scoping), extending performance schedules to match funding levels, terminating contracts, other contract or program restructuring, or taking alternative action to move or defer procurement costs to the future (Ferrell, 2).

From this, one can ascertain that the DoD must prioritize its acquisition programs in order to achieve the desired capability for the warfighter while maintaining a portfolio that is within the allotted budget. In order to do this the DoD will be required to cut back on non-critical programs and redefine quantity, schedule and possibly requirements of remaining programs as required and allowed by the contracting process. In light of this adverse climate contractors must take every possible action to ensure that program goals are met within the allotted budget and schedule.

7.2 SYSTEMS ENGINEERING

Systems Engineering is a discipline developed by both industry and the government for the purpose of managing the system development process. The Defense Acquisition Guidebook states that

> Balanced system solutions are best achieved by applying established systems engineering processes to the planning, development, and sustainment of a system or a system-of-systems (SoS) acquisition in an Integrated Product and Process Development (IPPD) framework … Systems engineering offers a technical framework to enable sound decision making relative to trade studies, system performance, risk, cost, and schedule. The successful instantiation of proven, disciplined systems engineering processes results in a total system solution that is adaptive to changing technical, production, and operating environments and to the needs of the use and is balanced among the multiple requirements, design considerations, design constraints, and program budgets (DAG 4.1.1).

Put more simply, Systems Engineering is a process for planning programs and ensuring that requirements are met by implementing a process for tracking and executing on their implementation. On a Major Defense Acquisition Program Systems Engineering is involved in every phase of the program from the preliminary design through the program termination (Figure 7.1). There are several different tasks undertaken as part of the systems engineering process including decision analysis, technical planning, technical assessment, requirements management, risk management, configuration management, data management and interface management and each of these is documented in section 4 of the Defense Acquisition Guidebook. The Defense Acquisition Guidebook provides an excellent overview of the required systems engineering processes on government acquisition programs however resources are also available from NASA and The International Council on Systems Engineering (INCOSE).

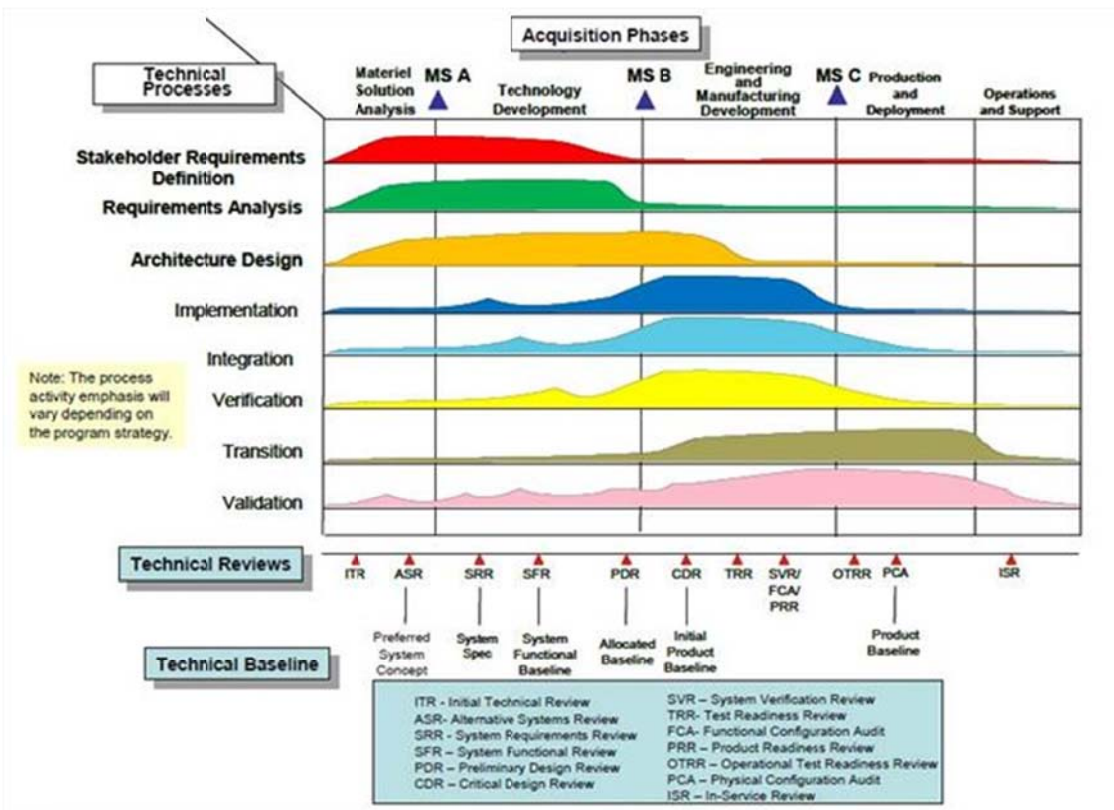

Figure 7.1 – Systems Engineering Phases in the Defense Acquisition Process (DAG 4.2.4.1)

Overall, the Systems Engineering framework is more than just requirements definition and management; proper implementation of systems engineering principles allows an engineering organization to evaluate technical risk, improve the estimating process, define and evaluate options for system development, perform trade studies and evaluate alternatives, and effectively structure and manage a development program. In addition there are defined procedures for developing the required specifications which document system, component, process and material performance and verification requirements. The systems engineering process also defines a clear procedure for executing technical reviews and meetings required during each phase of the program (DAU SEG 74). A diagram outlining the specification levels required is shown in Figure 7.2.

The Systems Engineering Process provides many valuable tools for improving program performance. The goal of the following evaluation will be to show how aspects of Systems Engineering can be incorporated into the development program to counteract the previously identified drivers of cost growth and improve program success.

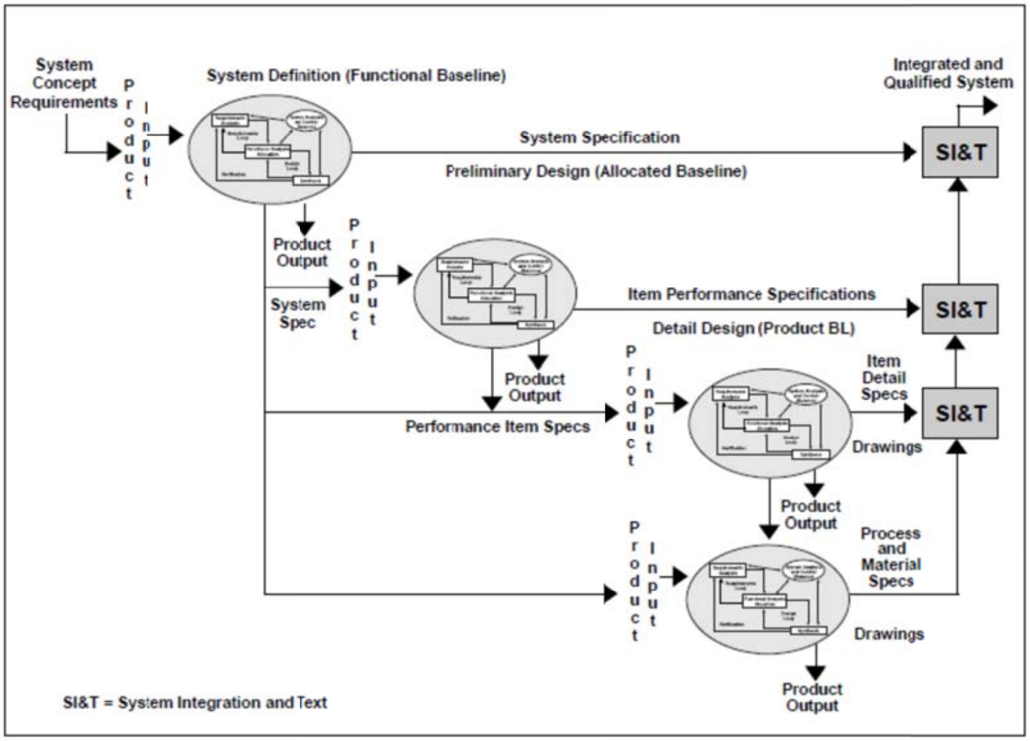

Figure 7.2 – Specification Levels (DAU Systems Engineering Guide 75)

7.3 Improving Program Management

In the case study comparing the F/A-22 and F/A-18 E/F Fighter Aircraft Development programs several program management aspects were highlighted as potential drivers of success or failure during the development process. Specific aspects noted were the implementation of the Integrated Product Team (IPT) Organizational Breakdown Structure, use of the Earned Value Management System for tracking program performance, proper Implementation of Management Reserve in the program budget and Implementation of an established work split and industrial base.

Systems Engineering practice defines clear guidelines for implementation of improved program management processes. Systems Engineering is a component of the DoD mandated Integrated Products and Processes Development (IPPD) Framework which implements an Organizational Breakdown Structure (OBS) composed of Integrated Product Teams (IPTs) to maximize the efficiency of design, manufacturing and supportability tasks (DAG 4.1.5). Systems Engineering is an IPT within the overall IPPD framework shown notionally in Figure 7.3. Systems Engineering is responsible for generating the program level Integrated Master Plan (IMP) and Integrated Master Schedule (IMS) as well as the Work Breakdown Structure (WBS). These three documents define the overall program milestones, program timeline and the individual work elements to be performed in executing the development program (Mitre). The Program level IMS and WBS also provide a baseline which is used to track program performance using the Earned Value Management System (EVMS). From the DAG

> Performance measurement of WBS elements, using objective measures, is essential for Earned Value Management and Technical Assessment activities to determine program progress. These objective measures are used to report progress in achieving milestones and should be integrated with Technical Performance Measures and Critical Technical Parameters (DAG 4.5.4.2).

As discussed earlier, EVMS is a tool for managing program performance by tracking work completed and cost actuals against an established program baseline. In tracking project performance the contractor reports hours used or and work completed to calculate the Actual Cost of Work Performed (ACWP) and Budgeted Cost of Work Performed (BCWP) for comparison against the Budgeted Cost of Work Scheduled (BCWS). When planning the initial schedule and budget a management reserve (MR) will be applied on top of the estimated budget at completion (BAC) to arrive at the total acquisition budget (TAB). A diagram illustrating the terminology and tracking methods used in EVMS can be seen in Figure 7.4.

Management Reserve is budget added to the program baseline estimate which has been withheld for dealing with unforeseen complications in the program. In the case for the F/A-18 E/F and F/A-22 it was discussed that the F/A-18 E/F planned a 10% MR while the F/A-22 had only 2%. Further, the allotted MR for the F/A-18 E/F lasted the full length of the program while the MR initially planned for the F/A-22 was consumed within 2 years. A study conducted by David Christensen of Southern Utah University evaluated the initial MR for approximately 500 DoD programs since the 1970s in order to determine a baseline for future MR estimates. The results of this study showed that the average MR for these programs was approximately 3 to 4% with a standard deviation of approximately 4% and a range of 0 to 28.3% (Christensen). Based on these results one can surmise that the data exhibits a log-normal distribution similar to that observed by Obaid Younossi for cost growth in Rand MG-588. Further evaluations could investigate Program Cost Growth versus the Initial Management Reserve however, from the analysis conducted by Christensen 4% appears to be the baseline and 10% has shown to be successful for the F/A-18 E/F.

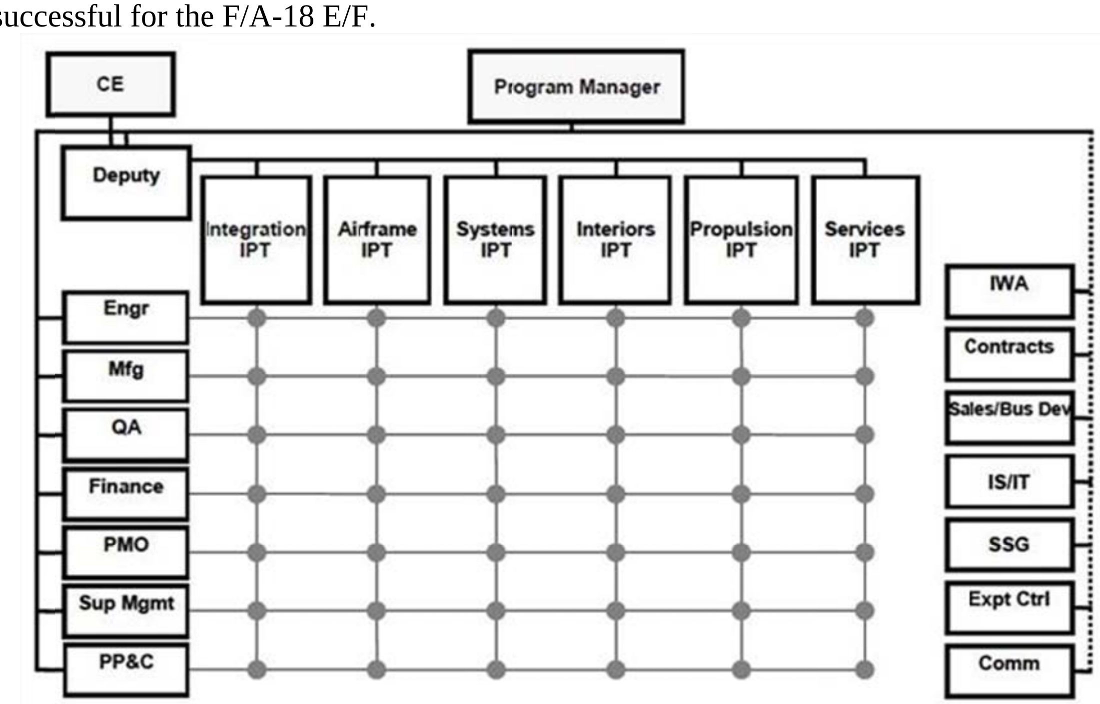

Figure 7.3 – Integrated Product and Process Development Framework (DAG 4.1.5)

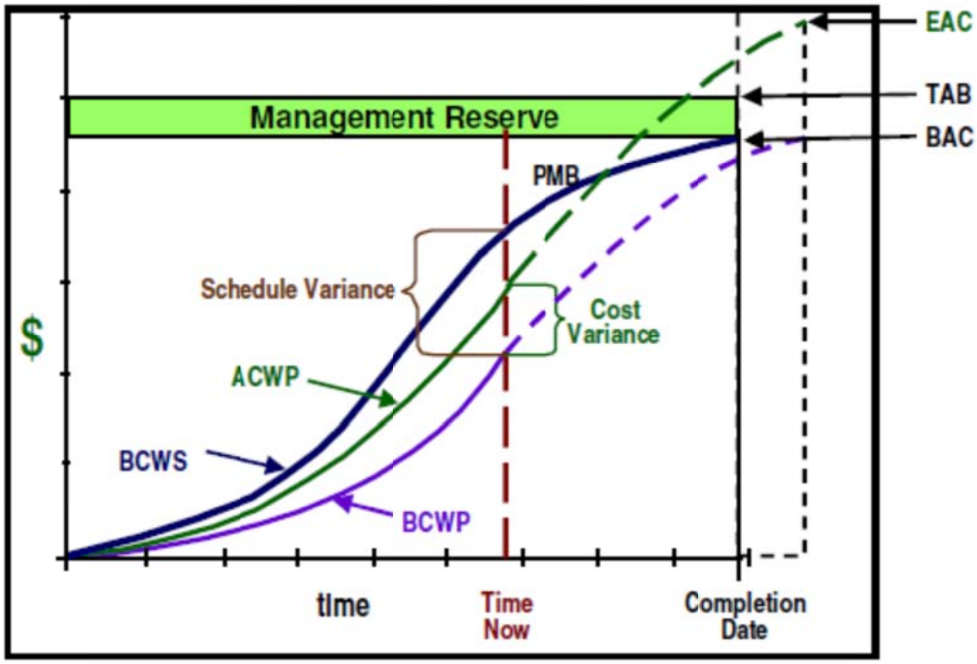

Figure 7.4 – Earned Value Management System (DAU Aquipedia)

7.4 IMPROVING SYSTEM REQUIREMENTS DEFINITION

In the previous discussion of the aircraft design process it was noted that when developing an aircraft system for a government customer the basic mission and design requirements for the system are supplied by the procuring body with the request for proposal. The requirements specification supplied by the customer will call out the key performance parameters (KPPs) and general mission requirements however the contractor must interpret these requirements into the final design. An excellent example of the outcome of this process can be seen in the YF-22 and YF-23 technology demonstrators; two strikingly different aircraft each designed to meet the same set of mission parameters. In this competitive environment it's critical that the requirements are properly interpreted and that the final product meets the customer expectations. As previously noted in the case study for the VH-71 Presidential Helicopter, the failure of the contractor to properly interpret and implement the program requirements was one factor which ultimately led to program cost growth and termination. The GAO recommendation going forward is to employ a Knowledge Based Acquisition strategy which requires specific systems engineering inputs at specific milestones in program development. The process, shown in Figure 7.5, contains 3 knowledge points implemented to ensure that a high level of program knowledge is available before commitments are made to move forward (GAO-233, 16). Knowledge point 1 occurs at MS B in the DAP and requires that, "Technology, time, funding and other resources match customer needs." At this point the PDR should be completed, all technologies should be demonstrated, Incremental Acquisition strategies are defined and a knowledge-based cost estimate has been defined. If all of the required conditions are met at this point then the, "Decision to invest in product development," will be made. Knowledge point 2 occurs at a point between MS B and MS C and requires that the, "Design is stable and performs as expected." At this point the program, "CDR and all subsystem design reviews [are] completed," 90% of all engineering is completed and, "an integrated system prototype [has been] demonstrated." Completion of this Knowledge Point precludes the decision to initiate build and verification testing of the, "production representative prototypes." Knowledge point 3 occurs at MS C and requires that the "Production [will] meet cost, schedule and quality targets." At this phase the, "Production representative prototype," has been evaluated in the mission environment, all manufacturing processes are ready, and "product reliability [has been] demonstrated [in] a production representative prototype." At the completion of this Knowledge Point the decision to produce initial customer units (LRIP) is then made (GAO-380, 9). The Knowledge Based Acquisition process is an extension of the Defense Acquisition Process which integrates systems engineering to ensure that key program deliverables are met prior to moving on to further phases of the development and production process. As previously noted, the VH-71 Presidential Helicopter was approved to enter simultaneous production and development efforts without the appropriate systems engineering process. As a result the program ultimately experienced significant cost growth and was determined to be inadequate after spending $3 bil. From this experience it's clear that the ability of a program to meet requirements must be established prior to initiation of development

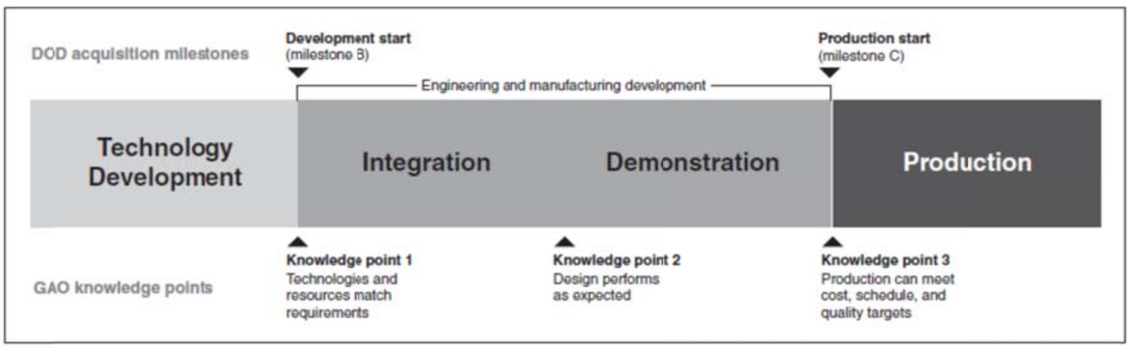

Figure 7.5 – Knowledge Based Acquisition Diagram (GAO-233, 17)

7.5 Improving Cost, Schedule and Technical Estimates

From the previous evaluation of cost in acquisition programs a significant factor identified to influence cost growth in acquisition programs was inadequate estimates of cost, schedule and technical uncertainty. In order to address these issues contractors must implement improved methods for evaluating the technology to be developed and improve the estimates for producing that technology. The following discussion will propose methods available for evaluating technical complexity and improving estimates of new technology programs.

Incorporation of the Systems Engineering Process in program development provides contractors with a toolset for improving cost estimates by incorporating the aspects of system integration into the estimating process as well as improving methods for integrating technical uncertainty. The Cask corporation points out that, “[The] DoD has been migrating away from a platform-centric approach in delivering capability to one of integrating hardware and software in the form of a System of Systems (SoS) to meet the unique requirements of end users” (Cask). In order to facilitate this, the Cask Corporation proposes that the ideal estimating team is comprised of Systems Engineers who will break down the system into constituent components and Cost Estimators who can generate the necessary cost analysis for the proposed system. This view is furthered by the Mitre Corporation in their Systems Engineering Guide which provides a high level view of the integration between Systems Engineering and the Cost Estimating Process. According to Mitre, “Systems engineers (SEs) are expected to use cost analysis to identify and quantify risks, and to evaluate competing systems/initiatives, proposals, and trade-offs ... SEs support and provide direction to the analyst, review results, guide and evaluate the sensitivity of the analysis, and provide technical, programmatic, and enterprise-wide perspectives and context for the analyst” (Mitre). The Mitre Corporation further provides a framework for implementation of the Cost Estimation Process in Conjunction with the Systems Engineering Process. The phases, Figure 7.6, involve defining the scope and assumptions of the estimate and linking the estimate to the project Work Breakdown Structure (WBS). In addition, by integrating Systems Engineering and the Project Estimate the Systems Engineer is able to more easily conduct trade studies and Analysis of Alternatives in support of the overall project definition. This is very valuable because, it will be noted that the ability to conduct trade-offs between cost and requirements was another lesson learned from the VH-71 program.

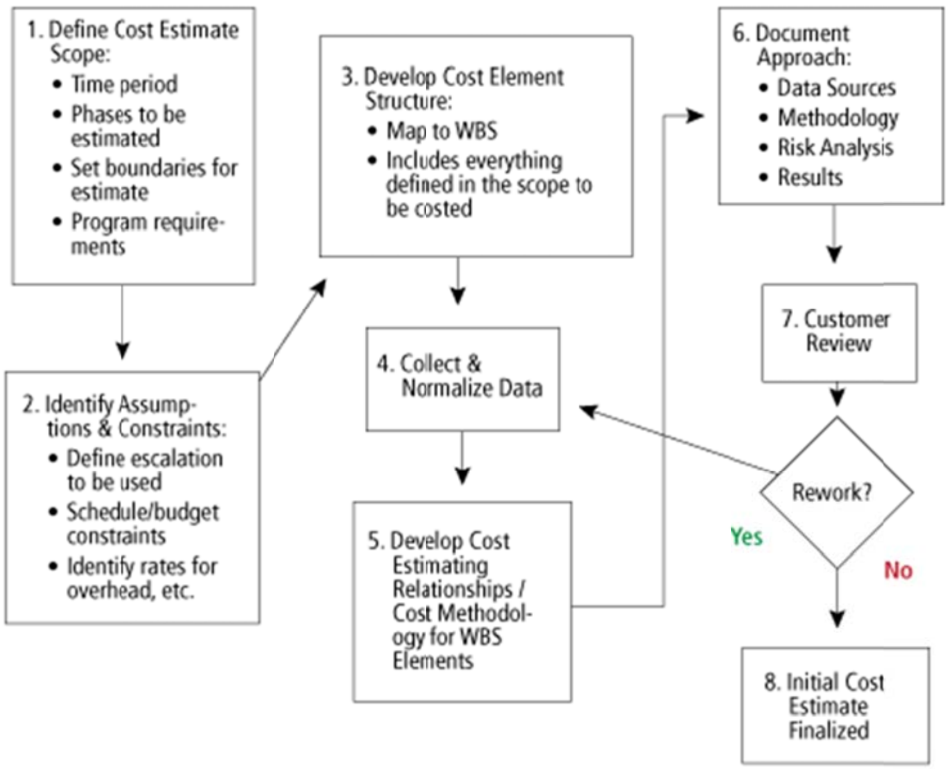

Figure 7.6 – Project Estimating Framework (Mitre)

Managing the Technical Uncertainty of a given project is integral in the estimating process. In the Mitre Project Estimating Framework it can be seen that Risk Analysis is a significant aspect of ensuring a quality cost estimate. Per Mitre, "Risk is an event that, if it occurs, adversely affects the ability of a project to achieve its outcome objectives. Risk management is the process of identifying risk, assessing risk, and taking steps to reduce risk to an acceptable level" (Mitre). In ascertaining the technical risk of a given project Mitre proposes using the widely accepted NASA Technology Readiness Level Scale.

The National Air and Space Administration (NASA) done extensive research on cost estimating and they have identified two scales referred to as Cost Readiness Level

(CRL) and Technology Readiness Level (TRL) for use in cost estimating efforts; Figure 7.7 shows the TRL scale. Technology Readiness Level is measured on a scale from 1 to 9 with 1 being the lowest level of undemonstrated new technology and 9 representing a mission proven fielded system (NASA SBIR). The scale for Cost Readiness Level is very similar to that for TRL, however it starts at 4. A CRL of 4 indicated that the cost estimate is very preliminary and has a variability of ± 45% while a CRL of 9 is applied to cost data from end of program actuals (NASA CRL).

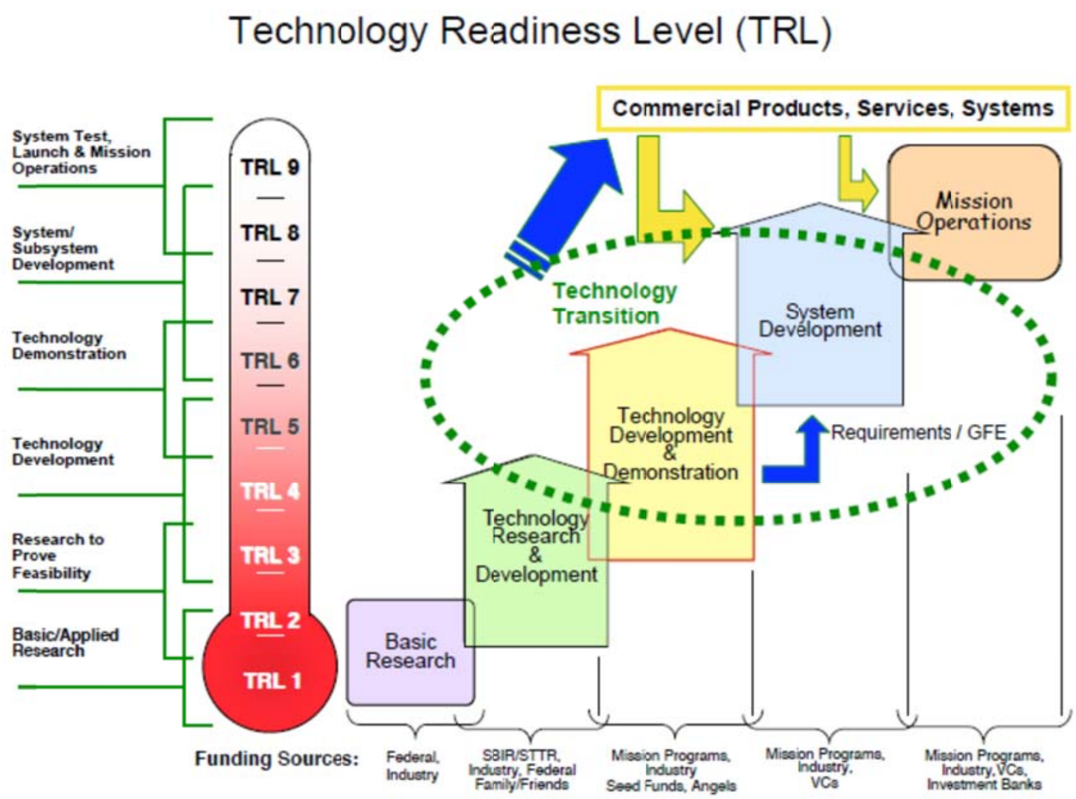

Figure 7.7 – NASA Technology Readiness Level Scale (NASA SBIR)

Mitre notes that while the TRL scales can be used to ascertain the risk of an individual technology element it does not address how well it will integrate into a project structure. Mitre points out that, "[Assessing Integration Risk] is an integral part of the systems engineering job and critical to the success of the technology transition" (Mitre). The Mitre Systems Engineering Guide further clarifies that an assessment of TRL is required in the Initial Capabilities Document (ICD) for all DoD programs, and that technologies with a TRL of less than 6 can increase the difficulty of program approval.

Other methods for incorporating technical uncertainty in estimating have been researched with the intent of drawing parallels to the techniques outlined in the systems engineering process. In "Developing Innovative Products on Budget and On Schedule -- Part 1," Glenn Havskjold Discusses Methods for utilizing previous development data to determine a correlation between technical uncertainty and development cost and John Reynolds of NASA has developed the Performance Based Estimating Tool with the intent of incorporating factors for technical uncertainty and team performance into the estimating process.

In the evaluation of causes of cost growth the work conducted on rocket engine development programs by Glenn Havskjold highlighted the link between technical uncertainty and the quantity of rework cycles required to complete the development of a high technology product. This parallels the findings from the evaluation of cost growth data conducted by Drezner and Younossi where one could ascertain that the disparity in cost growth between system types may infer that there are varying levels of technical uncertainty associated with different types of acquisition programs and systems. From the data, electronic systems were shown to exhibit lower cost growth while aircraft, missiles, helicopters and space systems exhibited increasingly larger values of average cost growth (Table 7.1). Further, the evaluations tended to show that modification programs based on established technology exhibit lower cost growth than new designs.

System Type	Cost Growth Data			
	Drezner		Younossi	
	CGF	n	CGF	n
Aircraft	1.28	14	1.35	9
Helicopter	1.13	5	1.76	3
Missile	1.17	44	1.52	8
Cruise Missile	-	-	1.64	4
Electronic	1.24	27	1.23	12
Electronic Aircraft	-	-	1.52	5
Munition	1.22	7	-	-
Vehicle	1.71	3	1.67	1
Space	1.16	3	-	-
Launch Vehicles	-	-	2.30	1
Satellites	-	-	1.55	2
Ship	1.10	14	-	-
Other	0.99	3	1.40	1
Source	RAND MR-291		RAND MG-588	

Table 7.1 – Cost Growth Factor Data Comparison

In the research pursued by Havskjold a correlation was shown between the quantity of rework cycles required and the technical uncertainty evaluated in the overall product as well as the subcomponents of specific rocket engine programs. Havskjold's work focuses on determining the cost of development based on the existing product development cycle in a given company with the intent of creating a tool to accurately predict the cost of new product development. He states that once an organization can ascertain within reasonable error the actual development cost of a new product then it will be possible to explore other methods for reducing the cost of rework cycles or reducing the level of technical uncertainty and therefore the overall quantity of rework cycles. In his work he further evolves this by showing a correlation between technical uncertainty and overall program cost. He then uses the data compiled to successfully predict the development cost of a new rocket engine (the RS-68). The most significant aspects of this research are the identification of a procedure for evaluating the technical uncertainty of proposed development and an identification of the threshold for unknown unknowns, essentially unknowns that will not be discovered until testing is initiated.

As discussed above, the National Air and Space Administration (NASA) has also done extensive research on cost estimating. Evolving on the previously discussed TRL scales, John Reynolds of NASA in collaboration with Boeing Developed the Performance Based Estimating Tool (P-BEAT) in order to incorporate additional complexity factors directly into the estimating environment. P-BEAT utilizes a standard database of actuals to derive Cost Estimating Relationships (CER) based on component mass and part count as well as the required materials and manufacturing processes, but also incorporates additional data for Product Life Cycle, Design Team Capability and Technology Readiness Level (Figure 7.8). The addition of the complexity factors allows the tool to incorporate complexity metrics which show the projected impact on the overall development cost (Figure 7.9). P-BEAT allows estimators to evaluate the cost required to improve the technology readiness level of a program as well as the impact of technology readiness level on the overall cost. Overall, the combination of Complexity and Parametric estimating factors allows the estimator to obtain greater estimate accuracy and improve confidence in the cost estimate.

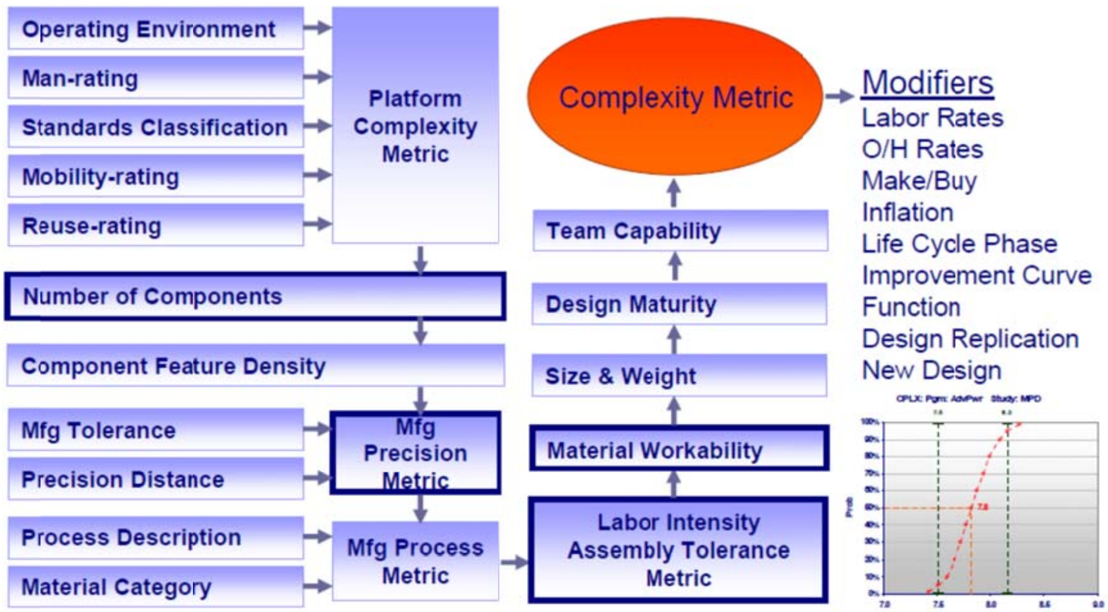

Figure 7.8 – Complexity Metric Development (Reynolds)

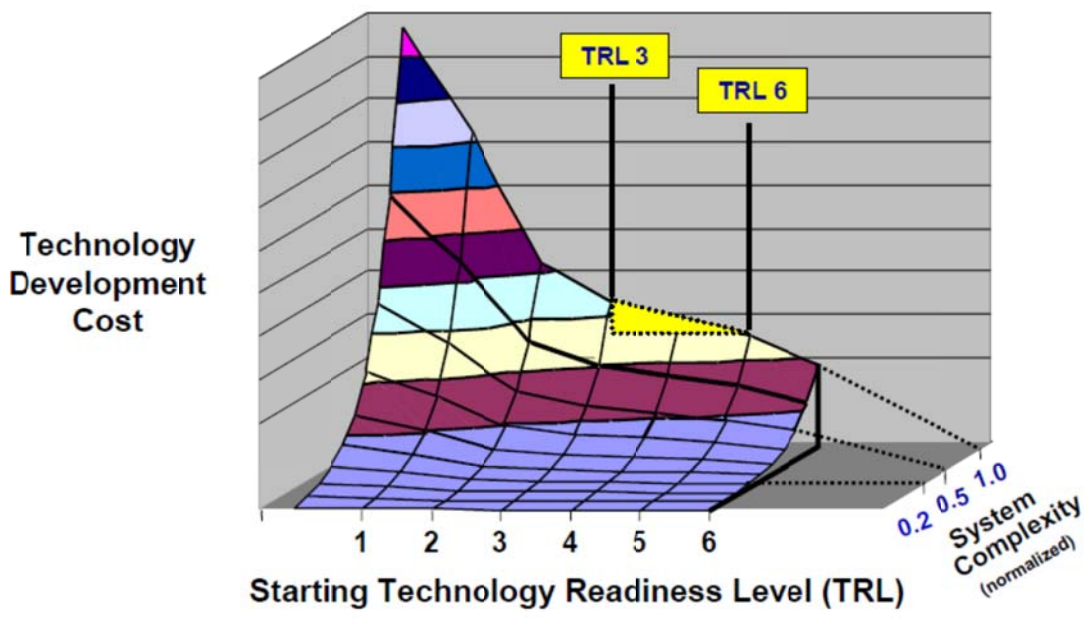

Figure 7.9 – Technology Development Cost vs TRL and System Complexity (Reynolds)

From the previous evaluation of cost in acquisition programs Inadequate estimates of cost, schedule and technical uncertainty were identified as significant recurring drivers of cost growth which a contractor can control. This evaluation has sought to propose methods which contractors can implement to improve estimates by integrating systems engineering and cost estimating processes as well as implementing advanced cost estimating techniques which account for technical uncertainty and design team experience. In addition, these changes will provide the capability for enhanced evaluation of requirements and cost trade-offs.

Systems Engineering is a discipline developed by both industry and the government which has been developed for the purpose of managing the system development process and it provides a toolset for contractors to use for increasing program efficiency. Implementation of systems engineering principles allows an engineering organization to manage requirements, evaluate technical risk, improve the estimating process, define and evaluate options for system development, perform trade studies and evaluate alternatives, and effectively structure and manage a development program.

In 2003 The INCOSE Systems Engineering Center of Excellence conducted a study on the value of systems engineering. In the study, Eric Honour, evaluates the effectiveness of systems engineering through several case studies and interviews of industry users. In addition he derives a systems engineering quality metric through interviews with program participants which he defines as the effectiveness of Systems Engineering Process implementation. Based on the evaluation conducted Honour determines that the ideal quantity of systems engineering in a given program is 15 to 20% if well executed, and further his findings indicated that this was relatively independent of actual program size. In the data depicted in Figure 7.10, Honour plots cost and schedule growth factors against a metric defined as the product of system engineering quality and the cost ratio of systems engineering for the program.

Program work split was discussed by Younossi as a differentiating factor for the Cost Growth of the F/A-22 vs the F/A-18 E/F program. The argument made by Younossi was that the established work split and industrial base used in the development of the F/A-18 E/F contributed to the success of the program by streamlining the development process via established roles and responsibilities. In contrast, Younossi argued that the artificial work split used in the development of the F/A-22 contributed to complexity in the development process which ultimately led to cost growth.

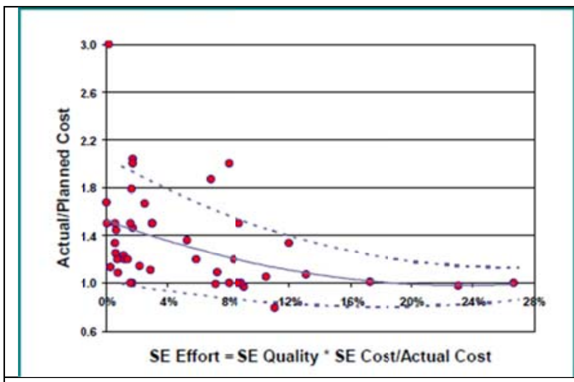	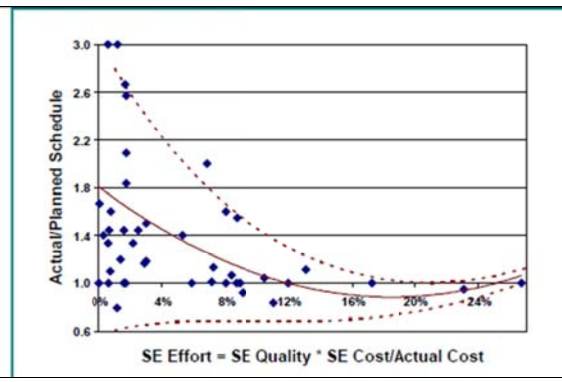
Cost Performance vs SE Effort	Schedule Performance vs SE Effort

Figure 7.10 – Systems Engineering Performance (Honour, 16)

In addition, Younossi argued that when the program relocated from the initial development site in Burbank California to Marietta Georgia only 10% of the initial development team moved with it which resulted in an engineering team lacking the experience required to execute the program effectively. This is a valuable observation because one must realize that Systems Engineering Processes can be used to establish program plans and work breakdown structures as well as provide tools for tracking the performance against those plans however it cannot design the aircraft. Systems engineering is a very powerful tool for improving program execution but it must be implemented in conjunction with an experienced team who can take advantage of the tools provided.

Of the factors which adversely affect the cost performance of acquisition programs some are within the control of the contractor such as errors in evaluating program requirements, errors in estimating the initial program schedule and cost, errors in estimating the technical complexity of the program and inadequate program management while other such as program requirements and quantity changes are outside of the control of the control of the contractor. As a developer of advanced systems one must be aware of the ever changing defense acquisition budget and realize that the DoD must prioritize its acquisition programs in order to achieve the desired capability for the warfighter while maintaining a portfolio that is within the allotted budget. In light of this adverse climate contractors must take every possible action to ensure that program goals are met within the allotted budget and schedule. The Systems Engineering Process provides many valuable tools for improving program success and the goal of the preceding evaluation was to show how aspects of Systems Engineering can be incorporated into the development program to counteract the previously identified drivers of cost growth and improve program success.

8.0 Conclusions

The preceding discussion has attempted to provide an overview of the Government Aircraft Acquisition Process with the goal of determining the primary drivers of cost increase in acquisition programs and methods for reducing or eliminating that growth. The Defense Acquisition Process was introduced to provide background on the phases of an acquisition program as well as to highlight the key points and deliverables. Aircraft Design was discussed with the goal of clarifying the basic process and the method through which the design is specified by the customer. Cost Data on aircraft programs was evaluated extensively with the goal of determining the primary causes which drive increasing cost in aircraft programs as well as to identify any significant trends. The results of the evaluation showed that the primary drivers of cost are Errors in Estimating, Technical Difficulty, Requirements Changes and Quantity Changes. Further, trends were found to exist for cost growth of different system types and new programs as opposed to upgrades. The discussion then moved to the topic of Nunn McCurdy Breaches where the criterion for and the results of a breach were clarified and data was provided to show historical trends. From the GAO, the primary causes of Nunn McCurdy Breaches were Engineering and Design issues, schedule issues and revised estimates which coincided well with the previous evaluations of program data. In addition, the data indicated a significant trend towards incurring breaches over the 12 year period evaluated.

Individual case studies were then considered in order to provide a detailed view of 3 different aircraft development programs. The F/A-22 Fighter was evaluated to show that high technical risk in conjunction with program management issues can drive cost while in contrast the F/A-18 E/F program showed that low technical risk and effective program management can result in a successful program. The F/A-22 experienced close to 80% Development Cost Growth and unit cost approximately tripled while the overall program cost was ultimately reduced. It should be noted though, that while the quantity adjustments allowed the DoD to contain the total program cost the final delivery will only be for 1/3 of the original planned quantity of aircraft. In stark contrast, the F/A-18 E/F came in on budget and schedule. The VH-71 Presidential Helicopter Program was also evaluated to show the impact of inadequate requirements definition and systems engineering. This program, planned as a mod to an existing airframe much like the F/A-18 E/F, was ultimately cancelled after it was projected to double in cost by completion.

The recommendations section offers a brief overview of the budgeting process and its impact on requirements and quantity changes which are, in many respects, outside of the control of the contractor. A discussion is then provided for the methods in which the systems engineering process can be utilized by contractors to correct the deficiencies identified which ultimately result in cost growth. Overall the intent of this study is to show how improved techniques for managing programs, meeting customer requirements and improving cost estimates can be implemented to manage cost growth when implemented in an effective engineering organization. Further data was then provided from a study by INCOSE to show how increasing the budget for project definition and management through systems engineering can result in improved cost performance.

The ultimate goal of this study is to show that risk can and should be managed more effectively and that high technology programs can be executed if they are properly managed.

Appendix A – Resources for the Defense Acquisition System

Topic	Source
Acquisition Procedure	Defense Acquisition Guidebook
Work Breakdown Structures (WBS)	MIL-HDBK-881A, Work Breakdown Structure
Configuration Management	ANSI/EIA-649, National Consensus Standard for Configuration Management MIL-HDBK-61A, Configuration Management
Earned Value Management System	ANSI/EIA-748A, Earned Value Management Systems DoD Earned Value Management Implementation Guide
Systems Engineering	NASA SE Handbook Systems Engineering Plan Preparation Guide
Risk Management	Risk Management Guide for DoD Acquisition
Manufacturing and Quality	MIL-HDBK-896, "Manufacturing and Quality Program NAVSO P-3687, "Producibility System Guidelines

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